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CONTENTS

Page 3 : THE FIRST MAIN-LINE DIESEL-ELECTRIC LOCOMOTIVE DELIVERED UNDER THE BRITISH RAILWAYS MODERNISATION PLAN.

9 : THE NAPIER ' GAZELLE ' 1,260-2,000 s.h.p. FREE TURBINE ENGINE.

22 : CONSIDERATIONS IN THE DESIGN OF OUTDOOR HIGH VOLTAGE SUBSTATIONS (PART II), *by A. R. Parish, B.Sc.(Eng.), A.M.I.E.E., Assoc. Mem.A.I.E.E., Switchgear Engineering Department.*

28 : A LARGE FLAX SPINNING MILL IN NORTHERN IRELAND, *by J. G. Winterbottom, Assoc.I.E.E., Assoc.A.I.E.E., Chief Engineer, Textile Division of The English Electric Company, and T. Getgood, A.M.I.Mech.E., M.Inst.F., Chief Engineer of the York Street Flax Spinning Company Limited*

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Type A 1,000 *h.p. diesel-electric locomotive built for British Railways by The English Electric Company and The Vulcan Foundry*

The First Main-Line Diesel-Electric Locomotive Delivered Under the British Railways Modernisation Plan

THE FIRST OF THE main-line diesel-electric locomotives ordered by the British Transport Commission as part of the railway modernisation programme was completed and handed over to the Commission on the 3rd of June 1957. This is a 1,000 h.p. Type A locomotive built by The English Electric Company Limited in conjunction with its associated company The Vulcan Foundry Limited.

Twenty of these mixed traffic locomotives have been ordered from The English Electric Company and are intended for operation on the London Midland Region of British Railways. They may be coupled together in multiple unit either with similar locomotives or with the Types B and C locomotives of 1,100 and 2,000 h.p. which the Company is also building for the British Transport Commission. They may also be coupled in multiple unit with many Types A, B and C locomotives of other manufacturers.

Principal Data

Wheel arrangement	Bo-Bo
Weight in working order	72 tons
Adhesive weight	72 tons
Maximum axle load	18 tons
Gauge	4 ft 8½ in
Length over buffer beams	43 ft 0 in
Overall width	8 ft 9 in
Overall height	12 ft 7⅜ in
Bogie wheelbase	8 ft 6 in
Bogie centres	24 ft 0 in
Wheel diameter	3 ft 7 in
Brakes	Air on locomotive, vacuum for train.
Diesel engine	'English Electric' 8SVT Mk.II, 1,000 b.h.p. at 850 r.p.m.
Maximum tractive effort	42,000 lb
Continuous rated tractive effort	19,500 lb
Maximum service speed	75 m.p.h.
Fuel tank capacity	400 gallons
Compressor	Westinghouse DVC3, motor-driven.
Exhauster	Reavell R8 × 8, motor-driven.
Radiator fan	Mechanically driven.
Minimum curve negotiable	3½ chains

Superstructure

The locomotive superstructure is of the bonnet type with a driving cab at one end. Doors are provided along the body sides to give ready access to the diesel-electric equipment.

The underframe is made up of four channel longitudinals divided into two pairs, each pair being joined at the top and bottom by plating, thereby forming two box sections ; these are cross-connected at intervals by transoms of welded construction. The centre part of the box sections is sealed off to form two fuel tanks, and they are connected together by two of the transom members which act as 'balancer pipes'. Drag boxes are welded to both ends of the underframe to carry the drawgear ; that fitted is of the standard British Railways screw coupling type, but provision is made for fitting buck-eye couplers.

Two battery boxes are underslung from the centre of the underframe. They are well ventilated, and ready access to the batteries for topping-up or removal is provided through drop-down hinged doors.

The superstructure side-framing is prefabricated and welded to the underframe. Removable roof sections are provided over the control cubicle, the

Fig. 1.—One of the Type A locomotives undergoing main line trials

power unit and the end compartment, to facilitate maintenance of the equipment. In addition, hinged hatches are provided over the cylinder heads, and a small removable hatch is provided over the superchargers. The cab is resiliently mounted on the underframe in order to reduce the noise level to a minimum.

Bogies

The bogie frames are of fabricated construction. The solebars are welded to form a box section, and the fabricated transom and headstocks are riveted to the solebars.

The load from the superstructure is transmitted to the bogie frames by a single bolster riding in each bogie. The bolster is carried on semi-elliptic laminated springs which are in turn carried on a spring plank supported from the bogie frame by inclined swing links. Springing between the bogie frame and the road wheels is provided by nests of coil springs which are located between the underside of the bogie frame and the top side of the equaliser beams. The forged steel equaliser beams are underslung from the roller bearing axleboxes. Forged steel hornclips are fitted on each side of the axlebox guides.

Manganese steel liners are fitted on the axlebox guides, axleboxes and the traction faces of the bolster and bogie transom. The lateral swing of the bolster is limited by rubber blocks.

Clasp-type brakes are fitted on all wheels, the air-brake cylinders being mounted on the bogie solebars and operating the brake gear through a system of levers and rods. The brake gear is the Oerlikon type manufactured by Davis and Metcalfe.

Layout of Equipment

The cab of the locomotive has two driving positions, for forward and reverse running. The engine compartment is behind the cab, and in addition to the power unit contains the control cubicle which is mounted transversely across the locomotive ; one side of the cubicle faces directly into the cab. The engine compartment also contains one of the traction motor blowers, and mounted on the bulkhead behind the power unit are the motor-driven fuel pump, lubricating oil priming pump and fuel filters.

Beyond the engine compartment is the fan compartment which contains the radiators, the roof mounted radiator fan, and the right-angle gearbox for the fan drive.

The end compartment contains the exhauster, compressor and the second traction motor blower.

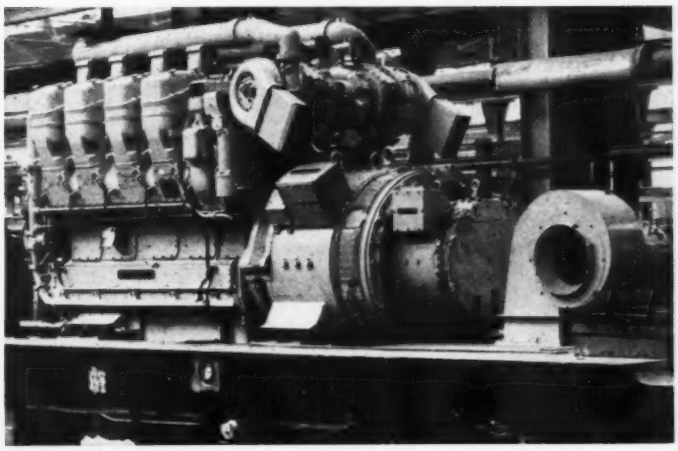


Fig. 3.
The diesel engine, generators and a traction motor blower, assembled on the locomotive underframe

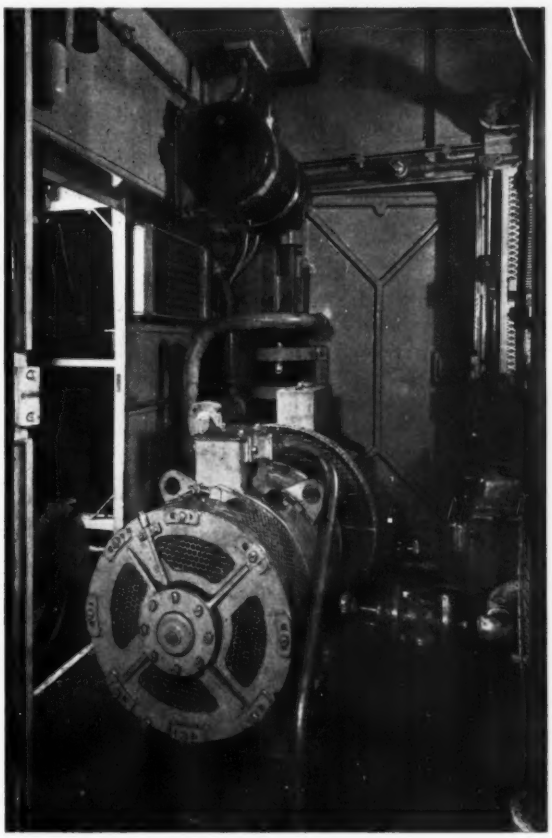


Fig. 2.—*Part of the end compartment containing exhauster, compressor and traction motor blower*

Oil wetted filters are provided in the sides of the locomotive, through which all air is taken into the interior.

The bulkhead between the fan and engine compartments is provided with openings through which the radiator fan is allowed to draw a large volume of air. This air enters the engine compartment through filters located towards the cab end, so that there is a flow of cooling air past the power unit.

The diesel engine and generators, together with one of the traction motor blowers, draw their air from the filtered supply in the engine room.

Air is drawn into the end compartment by the traction motor blower and compressor, through the filters in its sides.

Diesel Engine

The diesel engine is an eight-cylinder unit arranged in vee formation, there being two banks of four cylinders. The engine operates on the four-stroke cycle and is supercharged by two Napier exhaust-gas driven turbo-chargers.

The main generator is bolted solidly to the diesel engine, and these, with an overhung auxiliary generator, form a compact integral power unit which is supported on resilient bearers so that it is not subjected to stresses

due to normal flexing of the locomotive underframe. Removal of the power unit from the locomotive is a comparatively simple operation.

The engine oil and water are cooled by a double-bank radiator, one radiator panel being mounted at each side of the locomotive. The fan draws air across the radiator and expels it through the locomotive roof, and shutters controlled from the cab provide protection against frost. The temperature of the cooling water is automatically controlled by a thermostatic by-pass valve in the water system.

Main Generator

The main generator is a direct current, self ventilated, single bearing machine with a continuous rating of 1,070 amperes at 600 volts. The field has a separately excited winding for normal running and a series winding for use when the generator is connected across the battery for engine starting.

The electrical output from the generator to the traction motors is varied by simultaneous control of the diesel engine speed and generator field excitation.

Auxiliary Generator

The auxiliary generator is overhung from the free end of the main generator. It is a direct current, self ventilated machine, and its output voltage is maintained constant at 110 volts by a carbon pile voltage regulator.

The auxiliary generator provides the low voltage supply for charging the battery, operating the control gear, and driving the auxiliary machines.

Auxiliary Machines

There are an exhauster, a compressor and two traction motor blowers, all motor driven from the 110 volt d.c. supply.

The Reavell R8 × 8 exhauster provides the vacuum for operating the train brakes. This rotating-vane type of machine normally runs at approximately 1,000 r.p.m. but may be speeded-up under the control of the driver to approximately 1,500 r.p.m. should a more rapid release of the brakes be required.

The Westinghouse DVC3 compressor provides the compressed air supply for the locomotive brakes, horns, sanding gear and for operating the control gear.

The two blowers provide the air for ventilating the traction motors. They are centrifugal fans which are directly motor driven.

The radiator fan is roof-mounted and is mechanically driven from the end of the diesel engine crankshaft remote from the main generator. The drive is by a splined shaft with flexible couplings to a right-angle gearbox, from which the vertical drive to the fan is made through a shaft with flexible couplings interposed ; there is also a centrifugal clutch in the final drive to reduce the torque imposed on the fan when starting or stopping the engine.

Traction Motors

Four axle-hung nose-suspended series wound traction motors drive the road wheels through single reduction spur gearing. They have a continuous rating of 600 amperes at a nominal voltage of 300 volts. In order to extend the range of locomotive speeds over which full engine power is available, provision is made for field weakening by means of diverting resistances.

Each pair of motors is force-ventilated from the adjacent blower in the locomotive superstructure, the air being led from the blower by ducts and flexible bellows connections to the air inlet at the commutator end of the motor.

Control Gear

Most of the control gear is housed in the control cubicle, and the remainder, including the torque regulator and voltage regulator, is located behind the control cubicle on a bridge support which runs across the locomotive from cantrail to cantrail.

The traction motors are connected in two parallel groups across the main generator, each group comprising two motors in series. Tendency to wheel-slip is reduced by protection circuits, but should slip commence the driver is warned by an indicator light at the driving position, and automatically the tractive effort is reduced.

In the event of low lubricating oil pressure or low cooling water level, the diesel engine is automatically shut down.

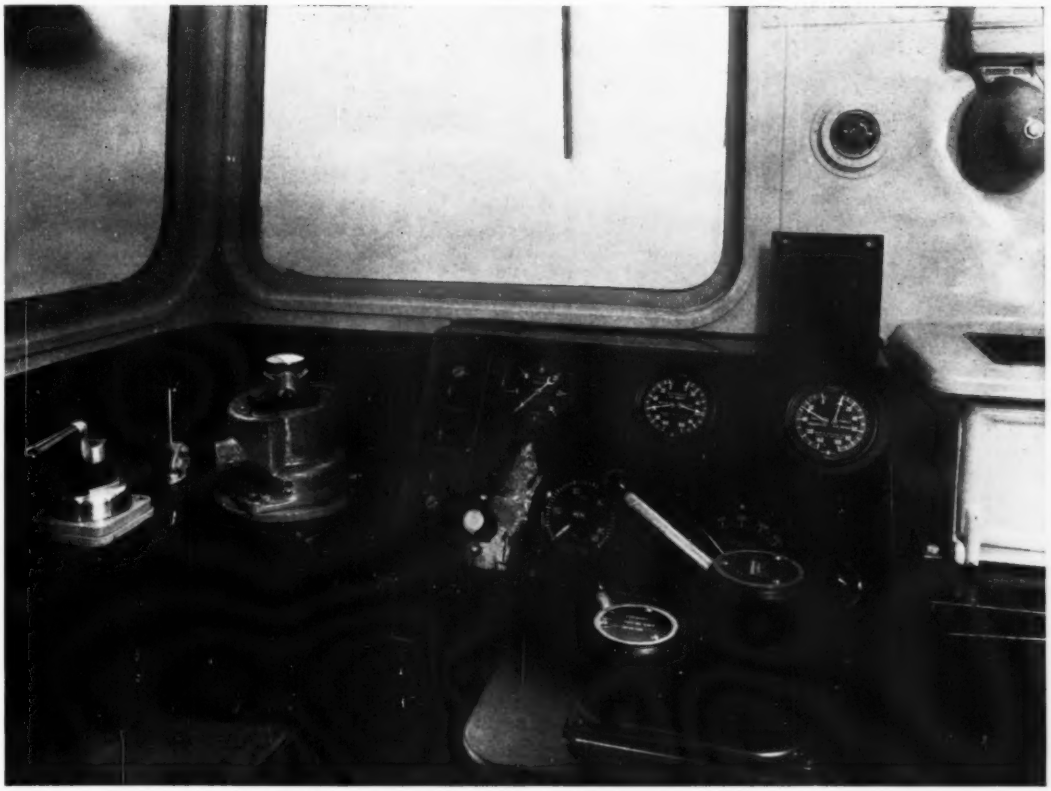


Fig. 4.—Driver's controls

There are two master controllers, one at each driving position, and the control circuits are energised by electro-pneumatic and electro-magnetic contactors and relays. The speed of the diesel engine may be continuously varied from 450 r.p.m. to 850 r.p.m., and the load on the engine is automatically adjusted to the maximum available power at the selected engine speed. The advantage of this system is that the diesel engine runs at the lowest speed at which the load demand can be met, with consequent economy in fuel consumption and minimum wear on the engine.

Driver's Controls

The driver's controls are very neatly built into prefabricated desks. There is a desk at each driving position, that nearest the control cubicle being a master desk but the locomotive can of course be driven with equal facility from either position.

The master controller is locked and made inoperative by a master key which prevents the locomotive from being driven by unauthorised persons. Once the controller has been unlocked, one of the two handles can be moved from the 'off' position to 'forward', 'reverse' or 'engine only'. The handle is first moved to the 'engine only' position, and the diesel engine is started by pressing a push button which connects the battery to the main generator, and motors the engine until it fires. Once the engine has fired, the handle can be moved to select the direction of travel. Thereafter, the locomotive power output is controlled by the second master controller handle. The controller handles and master key

Fig. 5.—Another view of the Type A locomotive during trials

are interlocked to prevent any mal-operation of the controls. The driver may change from one driving position to another without stopping the engine which has an independent 'engine stop' button control.

In addition to the master controller, there are the two brake handles at each driving position enabling the driver to select the vacuum train brake, or the air brake for the locomotive only. A vacuum/air proportional valve ensures that when a vacuum brake application is made on the train, there is an automatic proportional application of the locomotive air brake.

A 'deadman's' pedal at each driving position, when released, cuts off power and applies the locomotive and train brakes. An additional pedal operates the sanding gear.

At each driving position instruments and indicator lights show the operating conditions of the equipment, and give warning of faults. There are three air and vacuum gauges, a speedometer, an ammeter for the main generator current, and three indicator lights. One light indicates that the diesel engine has stopped, the second the existence of wheel-slip, and the third a fault condition such as high water temperature or the traction motor blowers not running.

Every consideration has been given to the comfort of the locomotive's crew. The seats are well upholstered, up to 4 kW of cab heating may be switched on, and a special heater has been built into each control desk to supply warm air to the driver's feet. A breakfast cooker is also provided in the cab.

The Napier 'Gazelle' 1,260-2,000 s.h.p. Free Turbine Engine

THE NAPIER 'GAZELLE' was designed primarily as a power unit for helicopters, but can function also as a propeller-turbine engine. One has already been installed in the prototype of the Westland 'Wessex' naval helicopter (basically a Sikorsky S.58), and two have been chosen for a special version of the Bristol 192, a twin-rotor military helicopter which is also to be built for commercial operation. In its commercial form, the Bristol will be known as the 192C. It will have a speed of 138 m.p.h. and accommodation for 16 passengers.

Test-bed running of the Gazelle began two months ahead of schedule. On its first run, the engine reached the output needed to pass its acceptance test—roughly, half its design power ; a few days later it logged its emergency rating of 1,260 s.h.p. It has completed a 25-hour special category test for flight clearance, and also its preliminary ground running and first flight in the prototype Wessex. In this very successful first flight of one hour, the Wessex was put through the full range of helicopter manoeuvres, and reached speeds of 125 and 35 knots in forward and sideways flight respectively.

The Gazelle can maintain a high power output whether the helicopter is in hovering or in forward flight—despite the wide disparity between the rotor speeds in these two conditions. Further, a sudden load does not tend to slow and stall the rotor, nor does a sudden lightening of the load cause over-speeding. Another advantage which the free-turbine type of gas-turbine offers is a steep drop in engine vibration and a corresponding drop in the number and magnitude of the problems created by it.

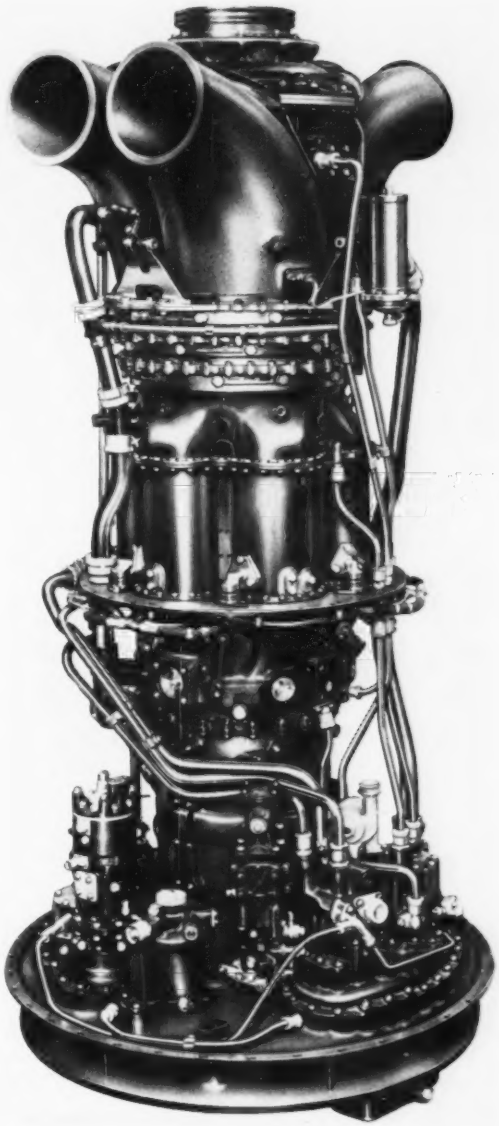


Fig. 1.—*Napier* '*Gazelle*' 1,260-2,000 *s.h.p. free-turbine engine*

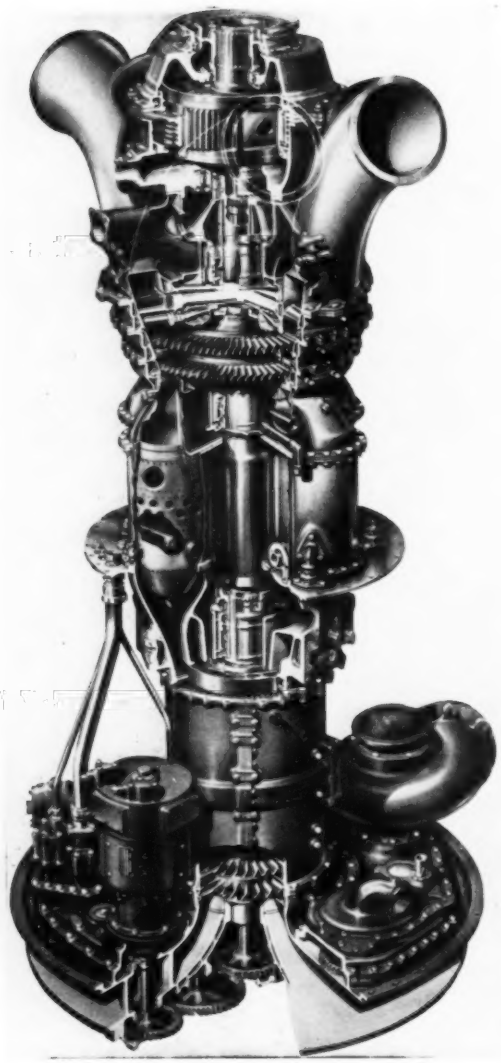


Fig. 2.—Cut-away view of Napier 'Gazelle' engine

At starting, with the rotor braked, the Gazelle can be run under 'no load' conditions—obviating the need for a clutch, and reducing the number and complication of the controls. At low power, optimum rotor speeds can be selected without loss of maximum compressor efficiency and fuel economy ; at maximum power, a rotor underspeed of 15 per cent. is permissible. Safeguarding devices built into the control system, in conjunction with safety features incorporated in individual components, provide both primary and secondary lines of defence against the failure of engine components and ensure that no single failure leads to uncontrolled flight or structural breakdown.

The engine can be mounted at any angle between vertical and horizontal to suit the installation, and can be supplied with either right-hand or left-hand rotation of the output shaft. The control system has been so designed that if one engine in a twin-engined installation fails, the power of the other is automatically increased up to a maximum of 30 per cent. in excess of the one-hour rating.

Main Features

The Gazelle (Figs. 1, 2 and 3) has an 11-stage axial flow compressor, six combustion chambers, a two-stage reaction turbine driving the compressor and a single-stage free power turbine coupled to the output shaft through an epicyclic reduction gear-box. Air enters the compressor through a radial intake and is delivered from the compressor to six flame tubes to which fuel is supplied through upstream injection burners. The combustion products pass through a two-stage turbine, which drives the compressor, and then through a bifurcated exhaust pipe. The power turbine shaft is situated within the bifurcation of the exhaust pipe and is coupled to an epicyclic reduction gear-box, incorporating a hydraulic torque-meter, from which the final drive is taken. The engine is controlled by a single lever, automatic compensation being provided for changes in flight conditions.

Leading Particulars and Performance

*Gazelle N.Ga.*1

Diameter (max.)	33·5 in (851 mm).
Length	70 in (1,778 mm).
Weight	780 lb (354 kg).
Weight/power ratio	0·62 lb/s.h.p. (0·28 kg/s.h.p.).
Fuel specification	D.E.R.D. 2482, 2486 or 2488. Kerosene JP-1, JP-4 or JP-5.
Oil specification	D.E.R.D. 2487, 7·6 cS viscosity at 100° C.
Fuel consumption (max. continuous)	0·77 lb/s.h.p./hr (0·35 kg/s.h.p./hr).
Oil consumption (normal)	1 lb/hr (0·45 kg/hr).
Rating : Emergency static	1,260 s.h.p.—20,400 compressor r.p.m.—sea level. Maximum output shaft speed 3,000 r.p.m.

One-hour static	1,100 s.h.p.—19,800 compressor r.p.m. —sea level. Maximum output shaft speed 3,000 r.p.m.
Maximum continuous static.	920 s.h.p.—19,000 compressor r.p.m. —sea level. Maximum output shaft speed 3,300 r.p.m.
Gazelle N.Ga.2 . .	Similar to N.Ga.1. Emergency rating 1,650 s.h.p.—20,400 compressor r.p.m. Weight of engine 830 lb (376 kg) + 2½%.
Gazelle N.Ga.3 . .	Similar to N.Ga.1. Emergency rating 1,800 s.h.p.—20,400 compressor r.p.m. Weight of engine 865 lb (392 kg) + 2½%.
Gazelle N.Ga.4 . .	Similar to N.Ga.1. Emergency rating 2,000 s.h.p.—20,400 compressor r.p.m. Weight of engine 900 lb (408 kg) + 2½%.

Performance curves are reproduced in Fig. 4.

Air Intake

The radial air intake to the compressor (Fig. 5) is cast in magnesium alloy (DTD.748). The intake provides a mounting for the engine accessories, and houses the variable inlet guide vanes. Protection against icing of the intake is provided by oil heated jackets, and the inlet guide vanes are anti-iced by passing through them hot air bled from the compressor.

Compressor

The 11-stage axial flow compressor (Figs. 6 and 7) has a constant outside diameter and supplies an air flow of approximately 16 lb per second at a pressure ratio of 6·37 to 1 at the emergency rating. The compressor gives optimum efficiencies which are well removed from surge throughout the entire speed range. At low engine speeds this margin

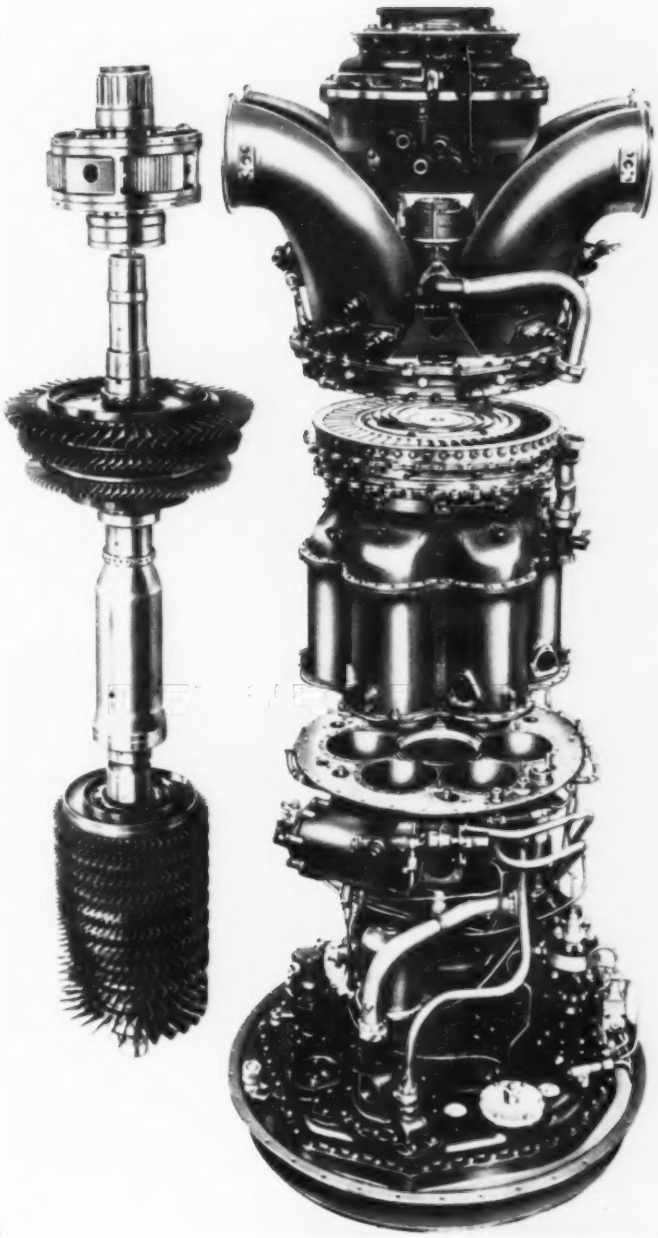
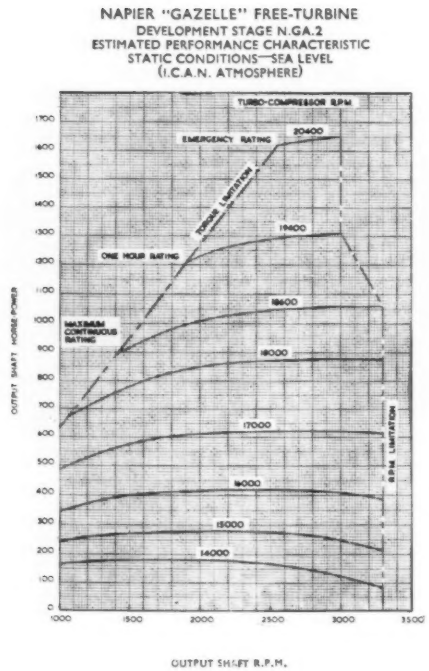
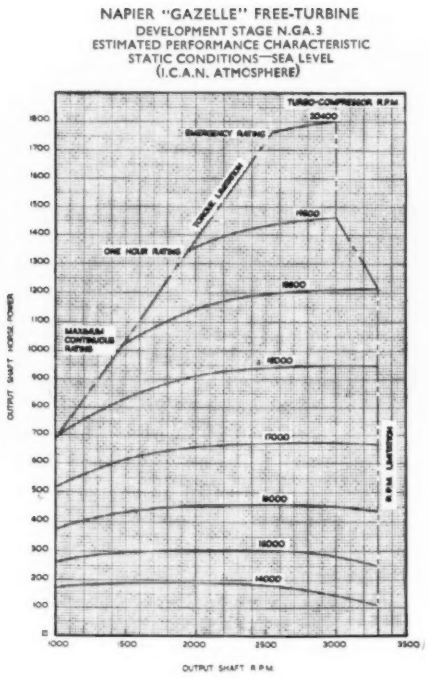
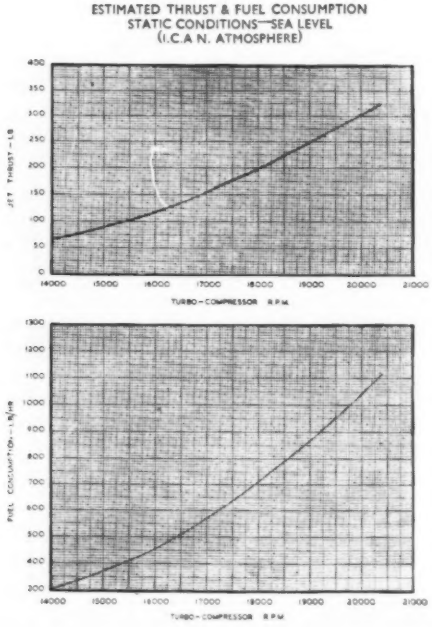


Fig. 3.—Exploded view of Napier 'Gazelle' engine







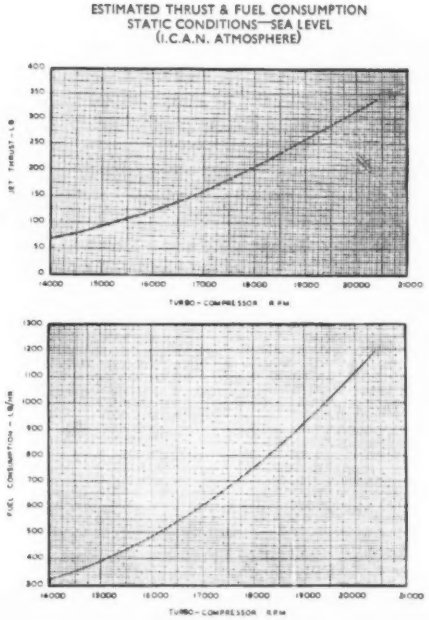


Fig. 4.—Performance curves for 'Gazelle' free-turbine engine

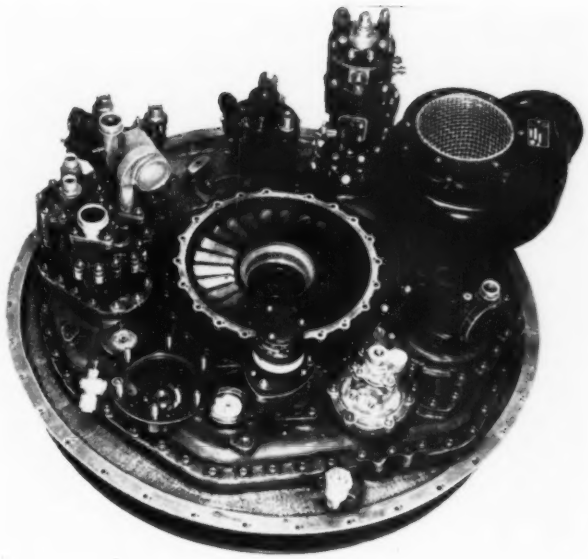


Fig. 5.—Air intake, showing inlet guide vanes and accessories

from surge is further increased by the use of variable incidence-angle inlet guide vanes controlled by a speed sensing servo unit.

Compressor blading is of aluminium bronze (DNS 210), a material which combines high fatigue strength with excellent corrosion resistance. All the rotor blades are secured by fir-tree roots to the compressor discs, which from stages two to seven are of aluminium (DNS 211) and the remainder are of steel (DNS 116-REX 448). The compressor casing, of ZT. 1 magnesium-zirconium alloy, carries the stator blading, the first three stages of which are shrouded. A roller bearing, situated in the air inlet casing, and a ball-bearing within the main support plate, carry the hollow steel (S 106) splined shaft.

Support Plate

The support plate (Figs. 8 and 9) is the structural foundation of the engine, having the compressor casing bolted to its lower face and the outer casing of the combustion system secured to its upper face. The casting is of ZT.1 magnesium alloy with four engine mounting pads cast integrally. The air delivered by the compressor passes through a delivery annulus and is diffused by six divergent ducts, leading to the combustion chambers.

Combustion System

The combustion system (Fig. 10) consists of a fabricated outer casing of Nimonic 75, containing six flame tubes of the same material. The six upstream burners are cooled by dilutionary air trapped in a shroud between the flame tube and casing, and can be individually removed without disturbing other components. The use of upstream burners has allowed a considerable shortening of the combustion system to be made, with a consequent saving in weight. Two high-energy sparking plugs are used to ignite the mixture on starting, and interconnector tubes between adjacent chambers ensure flame propagation and pressure balance. The engine operates satisfactorily on either kerosene or wide-cut fuels.

Turbine

The compressor turbine (Figs. 11 and 12) comprises two rotor discs of REX 448 steel splined on a hollow shaft forged from S.106 steel and carried

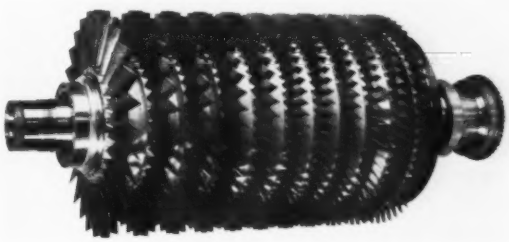


Fig. 6.—The compressor rotor

on a deep groove ball bearing. The turbine drives the compressor through internal gear-tooth splines on the turbine shaft engaging with a coupling splined to the compressor shaft.

The rotor blades are of Nimonic 100 in stage one and Nimonic 90 in stage two, secured to the

Fig. 7.—Compressor half-casings and stators

casing. A swinging link attachment on several of the inner platforms carries the inter-stage seal plate, allowing differential expansion and maintaining concentricity of the seals under all conditions.

Mounted co-axially with, but mechanically independent of, the compressor turbine is the free power turbine (Figs. 14 and 15), which is coupled to the output shaft through epicyclic gearing.

The forged power-turbine disc is integral with a hollow shaft carried on one ball bearing and one roller bearing. The blading is similar to that on the second-stage rotor blades of the compressor turbine. A splined quill shaft engaging on internal splines

discs by fir-tree roots and special locking tabs. A limited amount of blade tip rock is permitted to relieve blade root stresses arising from differential expansion of the blades and discs ; a Nimonic lacing wire (Fig. 13) running through the blade roots provides vibration damping. The inter-stage ring between the first and second stage rotor discs is of S.80 steel and is located on the shaft by a small diameter peg. After the second-stage rotor disc, a balancing disc incorporating screwed plugs is provided for the final dynamic balancing of the rotor assembly. Scroll-type deflectors on the inter-stage sealing assemblies control the passage of cooling air across the faces of the turbine discs. A balance piston, splined to the shaft before the first-stage rotor, limits the axial loading on the bearing imposed by the turbine thrust.

The first-stage nozzle blading is cast in X.40 steel and locked in slots on the inner and outer rings. The second and third stage nozzles have inner and outer platforms and are bolted to the external

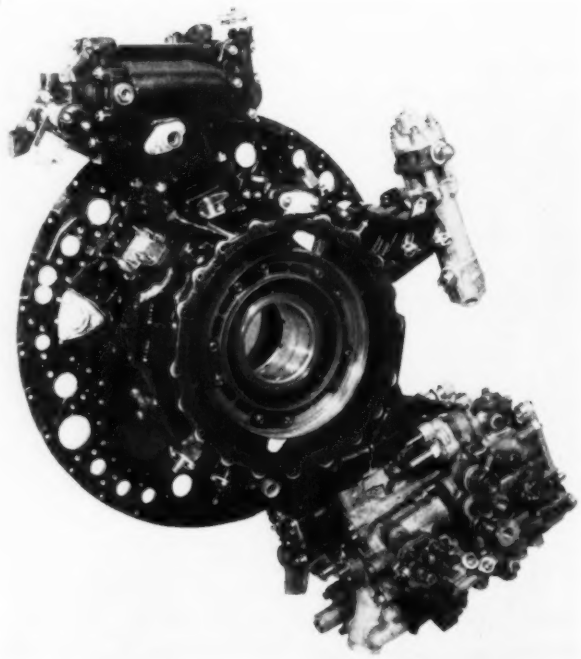


Fig. 8.—Support plate, looking downstream

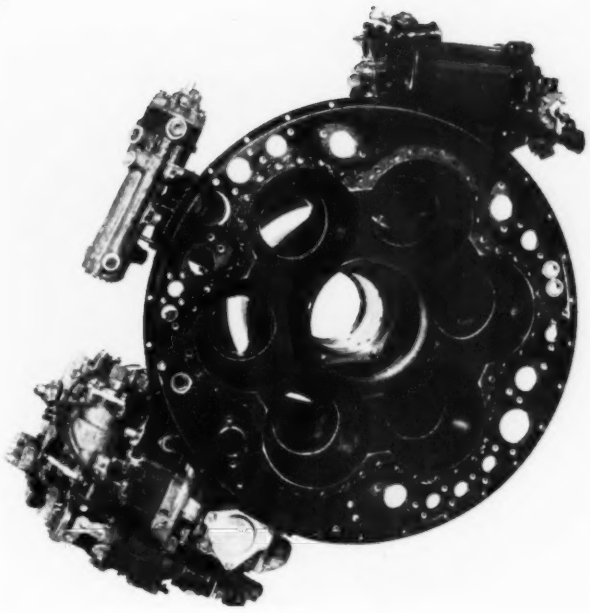


Fig. 9.—Support plate, looking upstream

in the turbine shaft transmits the drive to the reduction gearing.

Reduction Gear

Because of the construction of the torque-meter, the gearing (Figs. 16 and 17) is not mechanically fixed to the casing ; this reduces vibration to a minimum and improves transmission efficiency.

A toothed stationary coupling is provided on the magnesium reduction-gear housing to transmit the engine torque to the airframe.

From the turbine, power is transmitted through a quill shaft to a high-speed input pinion supported at the rear end by a ball bearing and at the front by a roller bearing. The pinion drives three planet gears, the layshaft of each being mounted on two roller bearings and carrying a planet meshed with the internal annulus gear.

The planet gear and layshaft assembly is carried on roller bearings in a carrier which is integral with the output shaft. The carrier is supported at the front end by a roller bearing and at the rear end by a ball bearing.

Torque-meter

The torque-meter (Fig. 16), which is mounted in the reduction gear casing, consists of an annulus gear and a torque ring, each having 15 vanes carrying spring-loaded seals. The annulus gear is located inside the torque ring so that the vanes on each are interposed and spring-loaded by the seals against the annular walls between the opposite members. The spaces between the vanes form the high and low pressure chambers of the torque-meter and allow peripheral movement of the annulus gear. During normal operation, oil is supplied by a high pressure pump through inlet ports to the high pressure chambers, and leaks across the sides of the vanes to fill the low pressure chambers.

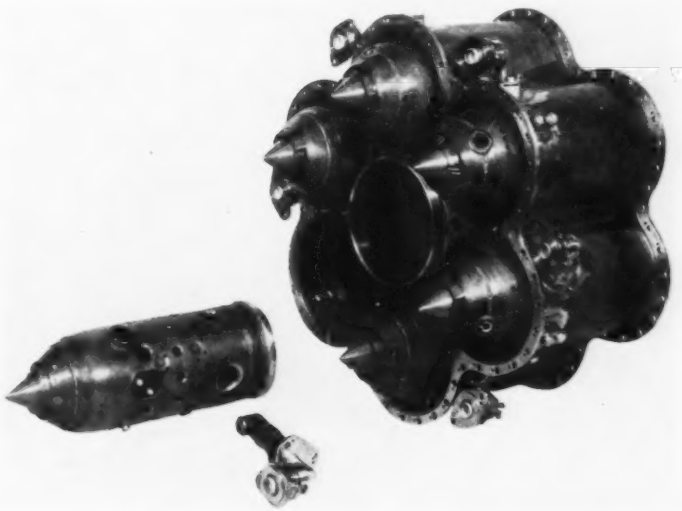


Fig. 10.—Combustion chamber, flame tube and burner

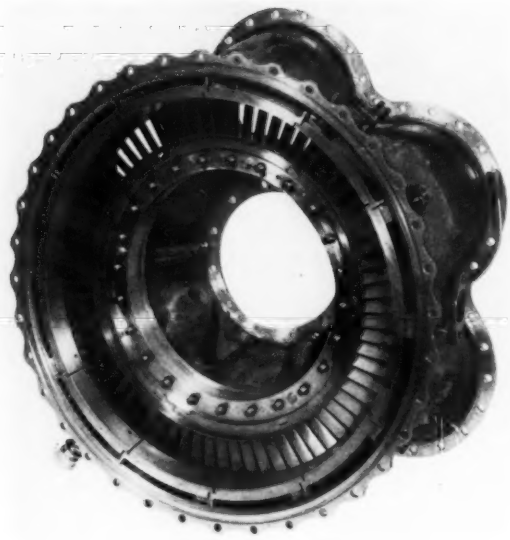


Fig. 11.—*Compressor turbine inlet casing and nozzle assembly*

The high and low pressure chambers are separately interconnected by annular passages, and drain oil escapes through exhaust ports in the torque ring front cover to the engine sump.

As the torque increases on the annulus gear, the vanes move in relation to those on the torque ring, increasing the inlet port area and thereby increasing the oil pressure in the high pressure chambers until the pressure is sufficient to balance the torque. Movement of the annulus gear also enlarges the exhaust port area to facilitate drainage of the now greater leakage of oil from the low pressure chambers.

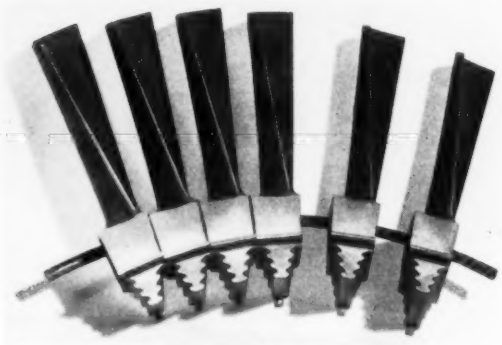


Fig. 13.—*Wire-lacing of turbine blades*

By suitable connections to the pressure balancing chambers the torque-meter is used to give signals for operating safety devices in the event of component failure.

Engine tests have consistently shown that the accuracy of the torque-meter over the normal power range is within $\pm$ 1% of the calibrated dynamometer readings.

Engine Cooling, Pressure Balancing and Sealing

Air is bled from the compressor to cool the turbine, to pressurize the balance pistons and bearing seals, and to protect the compressor inlet guide vanes from icing.

The front face of the first-stage turbine rotor is cooled by air tapped from the support plate. This air passes through an annulus at the outer diameter of the balance piston assembly, pressurizes the balance piston and then, through a small clearance between the seal plate and the hub of the balance piston, flows across the front face of the first-stage disc, through a scroll. The object of the scroll is to lengthen

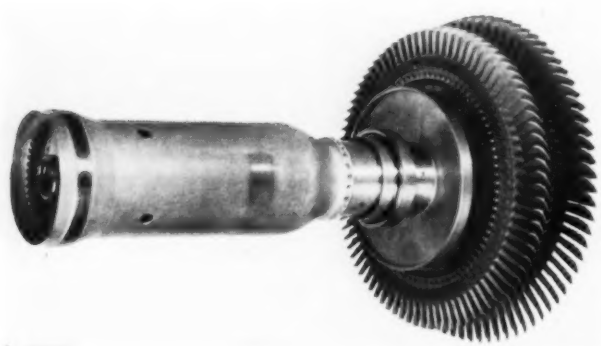


Fig. 12.—*Compressor turbine rotor*

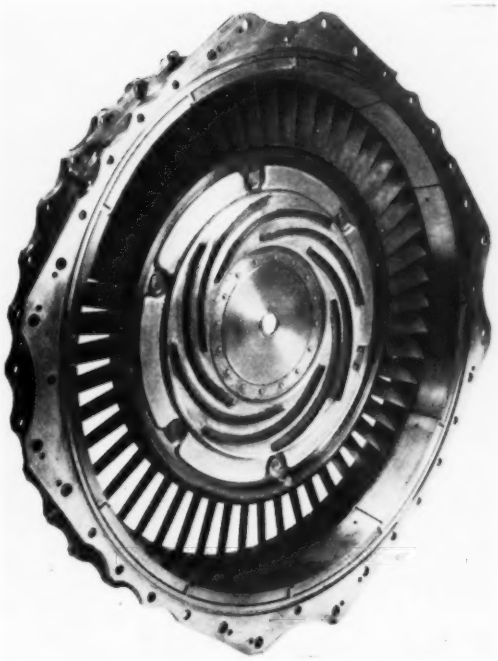


Fig. 14.—*Power turbine nozzle assembly and casing*

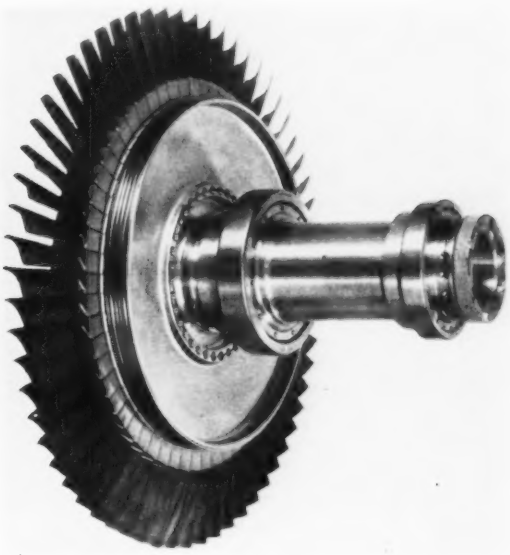


Fig. 15.—*Power turbine rotor*

the path of the cooling air across the face of the disc.

Further air is tapped from the tenth stage of the compressor and passes into the hollow shaft through an air transfer shroud carried at the inner diameter of the stator blading. This air, which passes through scrolls on the inter-stage seal plates, cools the rear face of stage-one disc, both faces of stage-two disc, and the front face of the free-turbine disc.

The power turbine bearing and the rear face of the last-stage disc are cooled in series with air taken externally through a pipe and filter from stage six of the compressor. Tappings from this

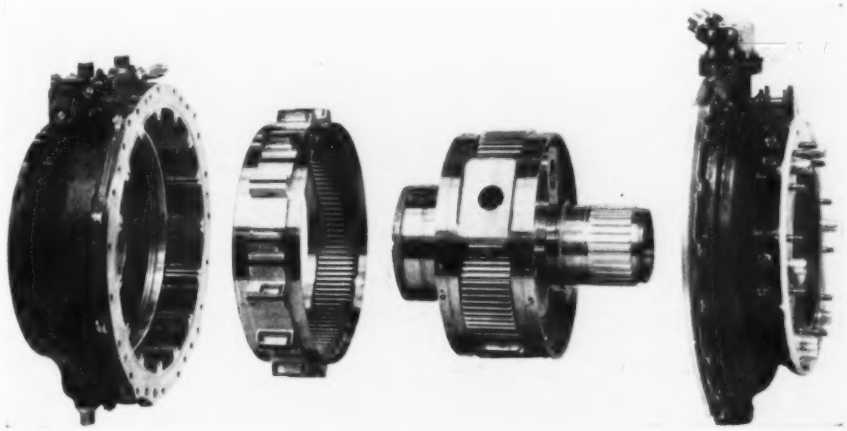


Fig. 16. *Reduction gear and torque-meter*

filtered supply also cool and pressurize the seals of the compressor delivery-end bearing and the compressor turbine bearing.

To heat the inlet guide vanes, air is taken externally from the compressor delivery. Stage four is also tapped to supply air, through the hollow compressor shaft, to the compressor balance piston and to pressurize the compressor inlet bearing seals.

Accessories

The engine accessories, comprising the electric starter, oil pumps, tachometer generator, speed sensing unit, centrifugal breather, oil cooler fan and fuel pump, are mounted on the air intake and disposed around the compressor. They are driven by a spur gear train from the front end of the compressor shaft, and the starter motors the engine through the same gear train.

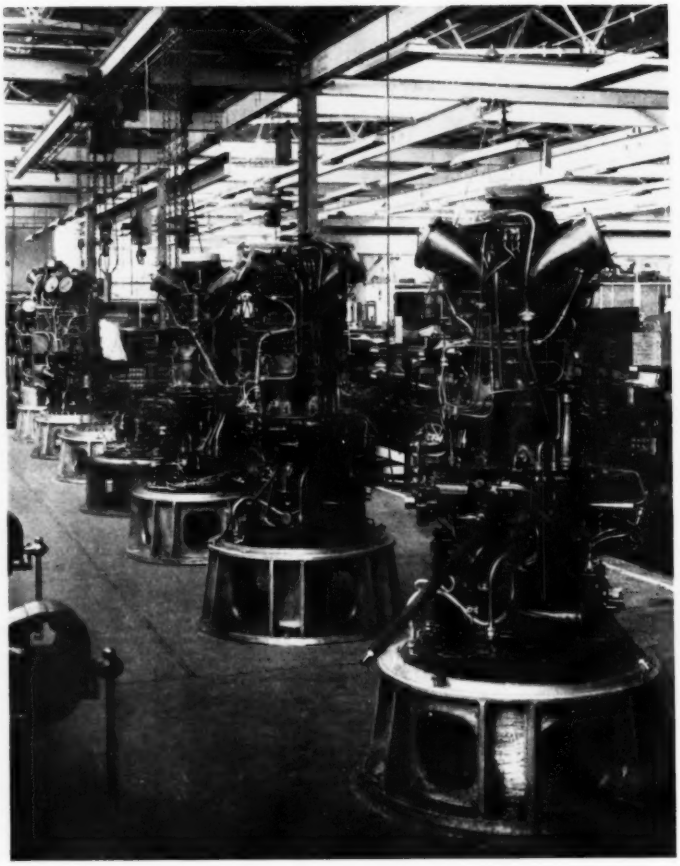


Fig. 18.—'Gazelle' engines in the assembly shop (above)

Fig. 17.—Exhaust duct and reduction gear mounting (below)

Lubrication System

Lubrication is on the dry sump principle, and the system has been designed to function satisfactorily in any installation position between vertical and horizontal.

The engine is supplied with oil from a gear-type pressure pump at 80 p.s.i. which, through a filter, delivers oil to the bearings, gears and torque-meter pump. The pressure pump incorporates a relief valve which by-passes excess oil, and a static head valve, situated between the pump and filter, prevents flooding of the engine by oil under shut-down conditions.

Oil passing through the filter into the oil feed gallery is fed through static head valves to the compressor delivery bearing, the compressor turbine bearings and the front bearing of the free turbine.

From the feed gallery, oil is also supplied for the lubrication of the reduction gearing through sparge-type jets on the planet carrier, and a metered feed provides lubrication to the rear bearing of the free turbine, the output shaft coupling splines and the reduction gear bearings.

The compressor intake bearings and the accessory bearings and gears are lubricated by oil taken from the intake side of the torque-meter pump.

Scavenge pumps are provided for scavenging the turbine and compressor bearings, feeding the oil to the auxiliary sump on the front face of the air intake casing. The oil is then transferred to the main sump on the free turbine casing, and after passing through a strainer and the anti-icing jackets in the air intake, is returned via the main scavenge pump to the aircraft system.

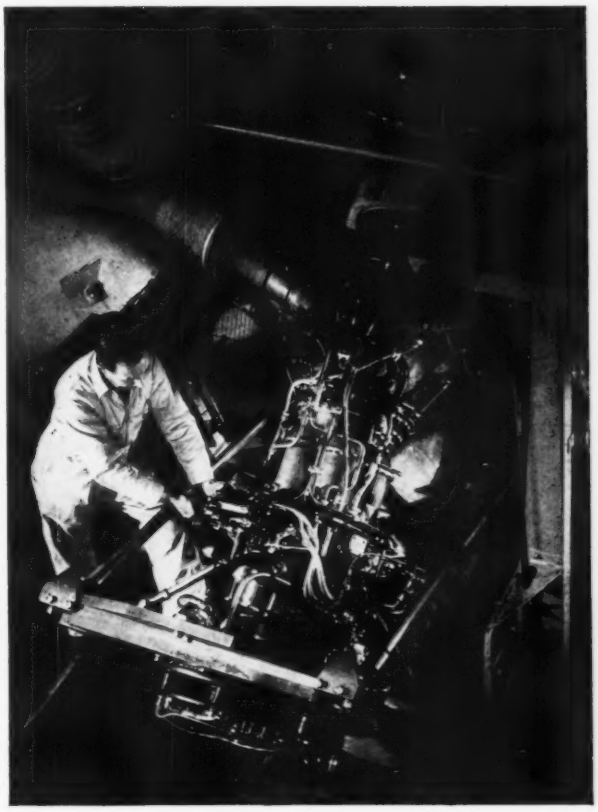


Fig. 19.—A 'Gazelle' engine on the test rig

Control

A single lever operating in a Napier fuel metering unit is the only engine control for normal running ; a second lever is required to dump the fuel. A Lucas variable-stroke pump supplies fuel to the metering unit ; automatic compensation of the flow for changes in ambient temperature and pressure conditions is provided by the unit, thus obviating any need for repeated control adjustments by the pilot. During acceleration the variable datum turbine inlet temperature and acceleration controls prevent over-fuelling which might result in surge of the compressor, and a control, responsive to engine speed, varies the compressor inlet guide vane setting. This enables the engine to accelerate rapidly, and 'slam' accelerations can be made. Should transmission failure occur, over-speeding of the free turbine is prevented by low positive-torque signals from the torque-meter causing the fuel metering unit to cut off the fuel supply to the engine immediately. With a twin engine installation, should there be loss of power due to the failure of one engine, the power of the working engine is automatically increased by an increase in the fuel flow, thus ensuring sufficient reserve power for a controlled landing or continuation of the flight path.

Maximum torque limitation is incorporated to prevent overloading of the transmission under extremely low ambient temperature conditions or incorrect rotor pitch angle.

This outdoor switching station, equipped with ' English Electric ' air-blast circuit-br
electric Commission of Tasmania. The Company has also supplied to this station t

cuit-brea a rating of 2,500 *MVA at* 110 *kV, is at the Tarraleah Power Station of the Hydro-ation thr h.p. impulse type water turbine generating sets operating under a head of* 940 *feet.*

Considerations in the Design of Outdoor High Voltage Substations

By A. R. PARISH, B.Sc.(Eng.), A.M.I.E.E., Assoc. Mem. A.I.E.E., Switchgear Engineering Department.

PART II

Part I of this article was published in the June 1957 *issue of this journal, volume fifteen, number two, page* 19.

Busbars

Both rigid tubing and stranded flexibles are used for busbars and connections, the choice depending largely on the layout of the substation. It has been the practice in the past to use copper almost exclusively for substation conductors, but economic circumstances are now causing much more interest in aluminium, with its substantially lower cost.

Where flexible conductors are used the problems are largely electrical, mechanical considerations being quite secondary. The principal electrical requirement other than adequate current rating (Table VII gives figures for commonly used sizes) is the avoidance of excessive corona discharge. Up to 132 kV normally stranded conductors can be used, but above this voltage specially stranded conductors are required. These consist of a core of copper tubes, or copper strip in helical form, over which the wire is stranded ; the result is a conductor of large outside diameter without an uneconomic copper content. In all flexible conductors hard drawn copper is used, so that there is a very generous safety margin between the maximum stringing tension and the ultimate tensile strength of any conductor of normal size.

TABLE VII

COMMONLY USED SIZES OF FLEXIBLE CONDUCTORS

Sectional Area square inches	Wire Diameter and Stranding	Current Rating amperes
0·15	19/·104	400
0·30	37/·104	600
0·40	37/·116	800
0·50	61/·104	1,200
0·75	91/·104	1,600

Rigid tubular busbars and connections present almost an exactly opposite case to that of flexible connections, in that mechanical problems are usually paramount. In normal conditions any installation which is mechanically satisfactory can be made adequate electrically. The obvious mechanical requirement is that the span shall not be such that, under the worst conditions of wind and ice loading, the copper is so stressed that a serious permanent set results. Unfortunately this is not the criterion which usually sets the limit, for it is necessary to consider the tendency of tubular bars to vibrate in a gentle breeze because of wind eddies formed on the lee side. In practice it is found that such vibrations are not serious if the natural frequency of the span is not less than 2·5 c/s. The Appendix shows that this condition is fulfilled for copper bars if the maximum sag in normal circumstances does not exceed 2 inches. It is found that for a wide range of wall thicknesses used with a given outside diameter of tube the maximum sag requirement of 2 inches results in the same permissible span. This is because the thicker walled tube although more rigid is also heavier, and the increased stiffness is cancelled by the greater weight. Thus the only satisfactory ways of increasing the permissible span are by an increase of outside diameter, by using copper-clad steel tube, or by rigidly fixing one or both ends of the span. In the last case, rigid fixing of one end permits 25% increase ; with both ends fixed 50% increase is permissible. However, it should be noted that 'rigid fixing' is in the structural engineering sense which requires that the bar where it leaves the support shall be constrained

into a truly horizontal position. In practice therefore it only applies where a busbar in one continuous length runs across a post insulator support to which it is rigidly fixed. Table VIII gives details of current rating and spans for some common sizes of tube for use in temperate climates.

TABLE VIII

CURRENT RATINGS AND SPANS FOR SOME COMMON SIZES OF TUBULAR CONDUCTORS

Outside diameter inches	Thickness S.W.G.	Max. Current* amperes	Max. Span feet
1¼	10	950	16
1½	10	1,100	17
1½	1	1,600	17
2	14	1,150	20
2	12	1,300	20
2	10	1,450	20
2	8	1,600	20
2	6	1,750	20
3	16	1,450	25
3	14	1,650	25
3	12	1,900	25
3	8	2,300	25
3	6	2,500	25

* For 50° C temperature rise.

The use of aluminium for substation conductors increases the permissible span by some 15% above that for copper tube of the same physical size and based on the same natural frequency. It is essential, however, to avoid direct contact between aluminium bars and copper or copper alloys in positions exposed to the weather if electrolytic corrosion is to be minimised ; plating of cuprous components or the use of aluminium fittings will avoid trouble.

Where flexible busbars are used it is necessary to study the tension, and consequent sag, at which they are to be erected. If the tension is too low, the sag will involve additional expense due to an increase of structure heights. On the other hand, excessive tension requires heavier and more expensive structures to carry the additional loading.

It is therefore usual to design for a maximum tension of 1,000 to 2,000 lb per conductor under the maximum loading conditions, which will be with the minimum design temperature and the maximum wind and ice loadings. However, the conductors will not be erected under such conditions and it is therefore necessary to calculate the appropriate tension for the erection conditions as well as the maximum sag under full load conditions at the maximum ambient temperature, to ensure that clearances are satisfactory. Where great accuracy is required such calculations become exceedingly lengthy and laborious, since account must be taken of the weights of insulators, fittings and droppers, and to some extent a trial and error process is involved.

Compressed Air Systems

Compressed air may be used to provide the power for closing an oil circuit-breaker or as the vital arc extinction medium in an air-blast circuit-breaker. For the former purpose the consumption of air is small, and failure of the air supply is a failure to safety. In the latter case however a large volume of air is required and continuity of supply is essential since without air the breaker cannot open when required. Thus two rather different problems arise.

For compressed-air operation of oil circuit-breakers it is the usual practice to provide a small air compressor-receiver unit for each circuit-breaker, except in very large stations where a central compressor plant may be more economical. With the local system the storage capacity is usually sufficient for two or three operations without recharging. A single small compressor is used but a connector is provided to allow a portable compressor to be coupled for maintenance purposes or in an emergency. With a central system the compressor would normally work at higher pressure and distribute to local receivers at each circuit-breaker at the lower working pressure ; in addition to local receivers at each breaker, there would also be a central storage of high pressure air.

For air-blast circuit-breakers a much more complex scheme is used in order to give the necessary security. Fig. 15 shows a typical scheme. It is of course essential to have dry air for the safe operation of an air-blast circuit-breaker, and this is most easily obtained without the use of chemical dryers by compressing the air to well above working pressure and then expanding it through a reducing valve to the working pressure. By this method moisture is condensed in the high-pressure receiver and must be drained off at intervals, but when the saturated high-pressure air expands through the

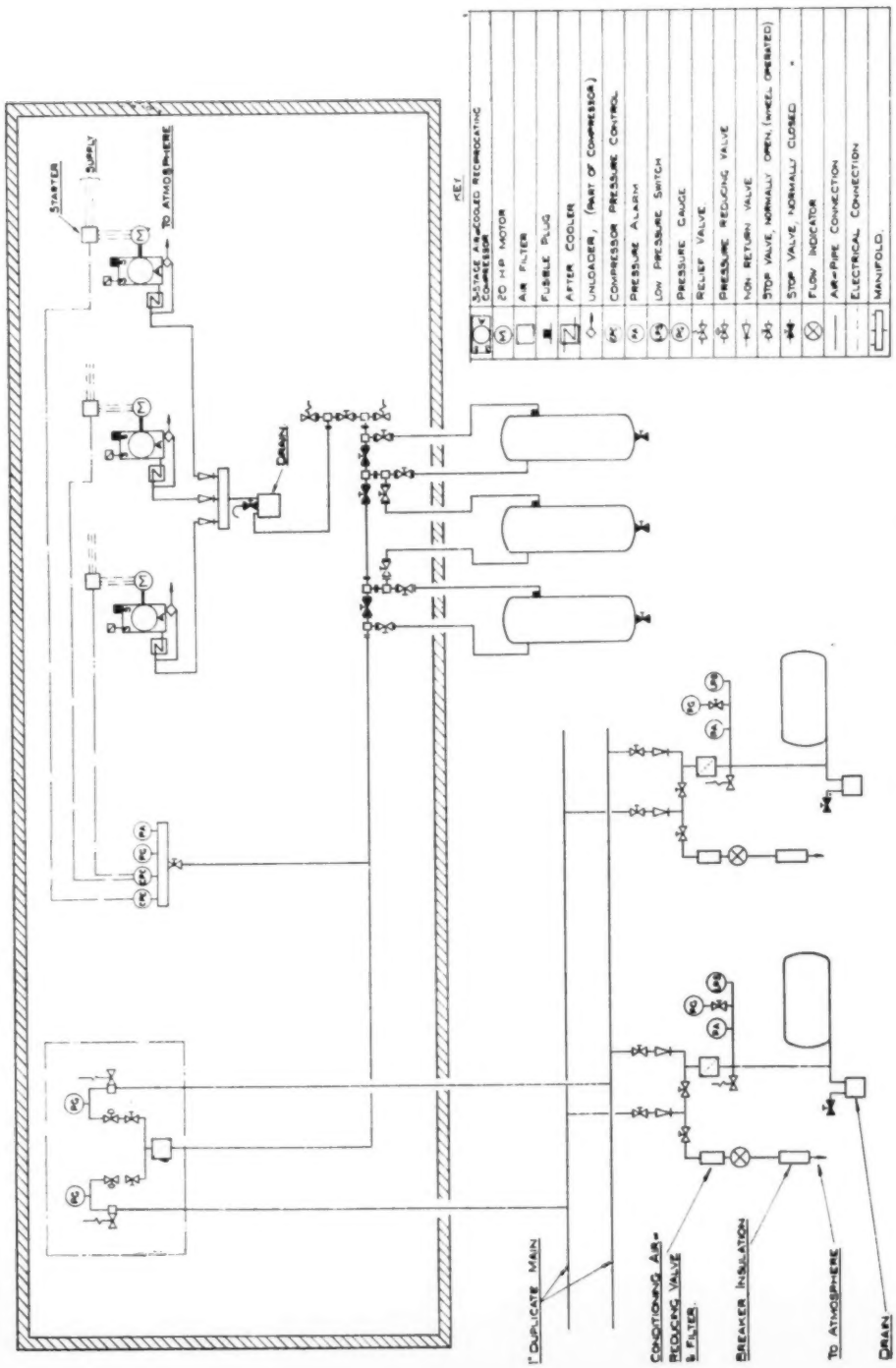


Fig. 15.—Typical air-pressure system for air-blast circuit-breakers

reducing valve it becomes dry due to the increase in volume. This is only true provided that (1) the design of the pressure reducing equipment is such as to prevent liquid water being carried over to the low-pressure side, and (2) for the normal pressure ratio of 2 : 1, the temperature difference between H.P. and L.P. systems is not more than 13°C. This latter point might cause difficulty if H.P. receivers were housed in a heated building, so allowing the H.P. air to hold a large amount of water vapour, while the L.P. system was outdoors under cold winter conditions, tending to cause condensation of the water vapour. This difficulty is avoided if the H.P. receivers are housed outdoors, but they may require to be shaded to prevent them being directly in the sun while the breaker receivers are in the shade. Further to minimise the possibility of moisture passing over, it is suggested that where more than one main receiver is provided they should be connected in series rather than parallel.

The amount of air which should be stored in the circuit-breaker local receivers and the main receivers depends on the duty required of the breakers, but in any case each local receiver would contain sufficient for at least one make-break operation. Air for a second operation of each breaker would normally also be available at high pressure in the central receiver, but auto-reclosing or other special duty cycles might well require additional air storage. As will be seen from Fig. 15, non-return valves and other safety features are provided so that a failure at one point in the air system shall not empty the storage facilities and sterilise breaker operation.

The pipework from the air supply system to the circuit-breakers is normally of ring main or ' double bus ' form to ensure continuity of supply. The piping itself is generally of solid drawn copper with mechanical compression fittings so that dirt and scale are not carried into the breaker with the consequent danger of blockage and mal-operation. The piping is laid in a concrete duct with about 1% slope to drain-vessels so that any entrained moisture is trapped. The size of pipe is determined by the time necessary to replenish the air in the circuit-breaker local receiver following a break operation ; a time of 3-5 minutes to restore 95% pressure is a common requirement and is very easily met. On most sites a refilling time of less than one minute is usual. The thickness of the piping depends on the working pressure and any special insurance requirements.

Various alternatives to the normal arrangement of copper piping in concrete ducts have been considered, but up to the present none of them has been used in Britain. The alternatives include the use of aluminium or synthetic pipe, and installation methods of direct burial in the ground or carrying above ground in racks and trays. There is so far no appreciable experience with any of these alternatives, and it remains to be seen how they stand the test of time.

Batteries

Storage batteries are used in substations to provide a reliable supply, unaffected by mains fluctuations and failures, for tripping and closing circuit-breakers, operating indicating lamps, and emergency lighting. In the great majority of cases lead-acid or nickel-cadmium-alkaline secondary batteries are used, but where tripping supplies only are required, primary cells of the Leclanché type are occasionally employed.

The battery equipment required for tripping only is relatively simple and in most cases a 30 volt battery of 10 to 25 ampere-hours capacity will suffice for normal installations. To maintain the battery in healthy condition and to supply such constant loads as indicating lamps, a dry plate rectifier is floated across the battery. A complete unit comprising battery, charger and control equipment can be obtained in a small self-contained floor mounting steel cabinet and this provides a most convenient arrangement.

Where a battery is used for a number of different duties such as solenoid closing of circuit-breakers, emergency operation of indicating lamps and semaphore indicators, and emergency lighting supplies, a unit of substantial size becomes necessary, 30 volts are inadequate due to the excessive voltage drop with the current involved, and 110 or 240 volts become desirable. In determining the required capacity of the battery for all these duties it is necessary to ensure in particular that it can perform its primary task of circuit-breaker closing and tripping at the end of an emergency period.

The capacity necessary for emergency conditions is easily calculated when the number of indicating

lamps and continuously energised semaphores is known, together with the consumption of the emergency lighting equipment. The duration of the emergency for which provision must be made will depend on local conditions but will usually be from one to three hours.

The capacity required for solenoid closing operations differs from that for the majority of loads on batteries, since the consumption in terms of ampere-hours is very small and the main consideration is the voltage drop due to the internal resistance of the cells. British Standard 116 requires that the voltage at the terminals of the closing solenoid coil shall be within 80% to 100% of the rated coil voltage. Some allowance must be made for voltage drop in the cabling between battery and circuit-breaker, and a figure of 5% is commonly allowed for this. Hence, to ensure satisfactory operation the battery voltage must not be allowed to fall below 85% of the nominal value. It is this requirement which dictates the battery rating for breaker closing by solenoid, and the ampere-hour capacity of the battery thus determined is added to that required for emergency loading, to obtain the total capacity.

Where bus-zone (busbar differential) protection is used, there is the possibility of a number of circuit-breakers being tripped simultaneously. With solenoid closed circuit-breakers the total current required for tripping will almost always be less than the current required for closing a circuit-breaker, so that the bus-zone tripping requirement adds nothing to the duty imposed on the battery. If however any closing means other than a solenoid is used, the bus-zone tripping requirement may add to the size of battery required for emergency duty and normal tripping. This is the case in stations using air-blast circuit-breakers, since the 'trip' and 'close' control valves have approximately the same consumption.

A battery used for substation work normally has a charger floated across it which supplies the standing load and any necessary trickle charge to replace its internal losses. There is therefore no charge-discharge cycle and it is possible to design special types of plates of lighter construction which permit the battery to give heavy momentary discharge currents with reduced internal voltage drop but which are not suitable for regular charge-discharge duty. Cells with such plates and low internal resistance are available for both acid and alkaline batteries. Since the solenoid and bus-zone tripping load limitations are imposed fundamentally by voltage rather than ampere-hour capacity, and the battery must comply with the 85% voltage limit at the end of the emergency period, any reduction of the internal resistance of the battery will show a considerable advantage and allow a substantially smaller battery to be used.

Lead-acid batteries are normally considered to have a nominal voltage of 2 volts/cell, so that to maintain a minimum of 85% nominal voltage a cell can be worked down to 1·7 volts. At the other extreme, 2·08 volts/cell are to be expected on trickle charge and 2·3 volts/cell on quick charge at the finishing rate. The voltage range from 1·7 to 2·08 volts/cell is quite acceptable for all apparatus. The higher voltages on quick charge involve no special precautions for normal solenoid and tripping duties, since the high voltage collapses very rapidly when load is applied, but it is necessary to provide manual or automatic means of tapping to a lower point on the battery to avoid overvoltage and premature failure of indicating lamps. Since the nominal voltage is 2 volts/cell it is usual to use, for example, 55 cells for a 110 volt battery. In some cases, however, up to 59 cells may be used to permit a lower ampere-hour capacity, and hence more economical, battery without the voltage falling below the 85% limit. This practice however requires careful consideration to avoiding excessive voltages during charging.

The nickel-cadmium-potassium hydroxide alkaline cell has a nominal voltage of 1·2 volts and so, within the 85% limit, can be worked down to 1·02 volts. While alkaline cells do not require trickle charging in the true sense, it is common practice to 'float' a rectifier across the battery to supply the continuous load ; in these circumstances the voltage is 1·23 volts/cell. While this is acceptable, the voltage on quick charge is such as to make end cell regulation necessary.

Charging equipment is normally based on selenium dry plate rectifiers for all but the largest chargers in which glass bulb mercury arc rectifiers are used. Motor-generator sets have almost entirely gone out of use, since the static equipment reduces maintenance, is more efficient, and is more

easily arranged for automatic or semi-automatic control, but where installed it is essential for the generator to have straight shunt excitation without compounding, to avoid danger if the mains supply fails. The charging equipment may be controlled entirely manually or partly automatically, or it may be entirely automatic in action when once switched on, the choice depending largely on the cost and reliability of the available maintenance personnel.

Fire Fighting Equipment

The use of large quantities of oil in transformers and switchgear is an obvious fire hazard. The danger can of course be reduced by using air-blast circuit-breakers, but oil filled transformers are universally used for the large sizes associated with outdoor substations. Consequently the transformer area will be the main concern in fire prevention, but small oil filled items such as voltage transformers require consideration. Hence it is common practice to provide permanent fire fighting equipment for transformers, particularly at generating stations and major substations, while the switchgear is covered by portable equipment.

For the permanent equipment protecting transformers either high-pressure water or foam may be used. The high-pressure water has the advantage of cleanliness when the incident is over, but it is essential that a completely reliable source of water at suitable pressure (80 to 100 p.s.i.) be made available, and this may be expensive. Foam apparatus may well result in a simpler installation, but care is necessary in the design to ensure that ' slabs ' of foam do not slide down vertical surfaces, such as those of transformer tanks, and so allow fire to start again. In general, carbon dioxide cannot be used outdoors because any wind will prevent a sufficient concentration being built up, but it may be a very useful adjunct to other fire fighting methods in dealing with oil burning beneath the base of a transformer, a place which is difficult to protect with other systems.

The portable equipment for use in the switchyard may consist of CO_2 or foam apparatus. Since this is intended only for dealing with minor outbreaks it is necessary to get close to the fire, and so it is essential to make the apparatus dead.

Apart from fire fighting apparatus, it is possible to minimise the effects of fire by precautions in the installation of transformers. A dwarf wall surrounding a transformer and of sufficient height to form a pound capable of holding all the oil in the transformer will prevent the spread of fire. If transformers are close together it may be advisable to separate them by a brick wall to prevent flames and heat from a damaged unit affecting a healthy one.

APPENDIX

Vibration, Deflection and Span of Busbars

The following are the relationships in a rigid busbar between vibration, deflection and span, referred to under ' Busbars ' on page 20.

For a beam freely supported at its ends :—

$$n = \frac{3{\cdot}52}{\sqrt{D}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad \text{(i)}$$

where n = natural frequency in cycles/second.
D = central deflection in inches.

Also, for a uniformly loaded beam freely supported at the ends :—

$$D = \frac{5WL^4}{384EI} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad \text{(ii)}$$

where D = central deflection in inches.
W = weight per inch run of beam in pounds.
L = length of beam between supports in inches.
E = Young's modulus in lb/in^2.
I = moment of inertia of beam in inches^4.

To avoid vibration troubles caused by wind eddies, a minimum natural frequency of 2·5 c/s is desirable. Hence, from (i) :—

D = 1·98 inches.

Substituting this value of D and taking E = 18×10^6 lb/in^2, equation (ii) gives :—

$$L = 229 \sqrt[4]{\frac{I}{W}}$$

If this expression is changed into the more commonly used units :—

$$L' = 35{\cdot}4 \sqrt[4]{\frac{I}{W'}}$$

where L' = length between supports in feet.
W' = weight per foot run of beam in pounds.

CORRECTION

In Part I of this article, in the second column on page 31, the statement that 90 tons of industrial dirt is deposited per *acre* should read *square mile*.

A Large Flax Spinning Mill in Northern Ireland

By J. G. WINTERBOTTOM, Assoc.I.E.E., Assoc.A.I.E.E., Chief Engineer, Textile Division of The English Electric Company, and T. GETGOOD, A.M.I.Mech.E., M.Inst.F., Chief Engineer of the York Street Flax Spinning Company Limited.

FOR MANY YEARS the progress in the British flax and linen industry has not been generally recognised. A general knowledge of the subject would seem to be restricted to those who have visited Northern Ireland and seen the remarkable achievements which have taken place there in recent times.

Flax appears in many articles in common use to-day. It is found in linen wearing apparel, linen handkerchiefs, shoe laces and stitching threads, fishing nets and angler's lines, ropes, insulation tapes, and the finest lawn fabrics and damasks, to name only a few of its applications. It is not generally known that linen fabrics were also produced by the ancient Egyptians for the preparation of mummy cases. The linen they used was of an extraordinary fineness in texture, and its finish was remarkably good.

France and Belgium were at one time the main centres for linen production, and their goods were exported all over the world. The finest flax is still grown and scutched in Belgium and is known as the Courtrai Flax. At the present time, however, Northern Ireland ranks as the principal world

Fig. 1.—*A general view of the York Street flax spinning mill*

producer of linen goods. This long established local industry can be readily attributed to the moist mild climate, which is so necessary in processing the material through its several stages of manufacture.

This article describes one of the largest flax spinning mills in the world, situated in Northern Ireland, and indicates the power requirements of such a mill for the many processes involved in the manufacture of linen.

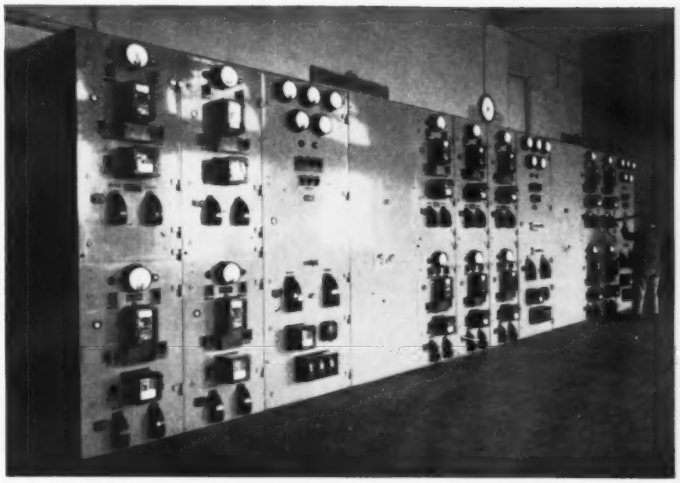


Fig. 2.—The main distribution air-break switchboard

The York Street Flax Spinning Company

A cotton mill in Belfast owned by two brothers, Thomas and Andrew Mulholland, was destroyed by fire in the year 1828. They immediately built a new mill in York Street, but instead of devoting their efforts to cotton, they decided to open as a flax spinning concern. This was to be the first power-driven flax spinning mill in Northern Ireland, and the new firm became well known under the name of Andrew Mulholland and Sons.

In 1851 the name of the firm was changed to the York Street Flax Spinning Company, being formed into a limited company in 1864 under the chairmanship of Mr. O. B. Graham, grandfather of Lt.-Colonel O. B. Graham, D.S.O., O.B.E., one of the present Managing Directors.

Gradually further mills, factories and warehouses were added at York Road, Henry Street and Courtrai Street in Belfast, with finishing works at Muckomore, Co. Antrim, and a stitching factory at Lurgan, Co. Armagh. By 1934 the York Street Flax Spinning Co. Ltd. had grown into one of the largest companies engaged in flax spinning and linen manufacture in the world.

During the Second World War, in 1941, a landmine wrecked the preparing mill, and the factory at Courtrai Street was gutted by fire bombs. Work started immediately on repairing the damage, but only a few weeks later high explosive and incendiary bombs demolished the Henry Street mill and factory, and partially destroyed the York Road mill. Only the power house and part of another building then remained on the Henry Street site. Now, in York Street, a magnificent new building with clean and functional lines has risen from the ashes (Fig. 1).

The rebuilding of the warehouse and administrative offices was completed in 1950 by F. B. McKee & Co. Ltd., and the mill was completed in 1955 by McLaughlin & Harvey Ltd. The architect was the late Mr. J. H. Stevenson of Samuel Stevenson & Sons, Belfast.

The reconstruction of the mill was carried out only after considerable research into the current practice and most modern productive methods in various countries including the United States of America and England in order to make it the most up-to-date spinning mill in the world.

The electrical power equipment for the mill, including the motor drives for the textile machines, the overhead busbars and the main and auxiliary switchboards, was supplied by The English Electric Company and installed by James Crawford (Electrical) Ltd., Belfast.

Mill Electrification

The flexibility of the electrical drive for textile machinery is now widely appreciated, and a close study of the numerous processes involved in the

manufacture of the final product, together with charted times of machine operation and work load, led to the decision to employ individual electric motor drive to each productive machine in this mill. Time intervals for doffing or replenishment of the various preparation machines indicated that more efficient operation and energy consumption could be attained with individual drives than with the alternative methods of group and semi-group driving from overhead line shafts involving large transmissions with their inherent mechanical losses. Individually driven machines can be run independently.

Seven hundred motors totalling 3,460 h.p. were installed. For all the productive machinery, and ancillary machinery situated within the productive areas of the mill, totally enclosed squirrel-cage motors were provided. For the drawing, roving and spinning machines the motors were designed with smooth acceleration characteristics to avoid breakages in the sliver and yarn fibres. Each motor is controlled by a push-button operated direct-on-line contactor starter with isolator. The motors driving the fans, pumps and auxiliaries of the air cleaning plants are of the screen protected and totally enclosed types.

The amount of electrical power required for a modern flax spinning mill is considerable. In assessing the overall power consumption of the York Street mill and the adjacent warehouse and office administrative block, it was estimated that some 2,500 kilowatts would be necessary. Since solid fuel has to be imported into Northern Ireland, it was decided to take the total power supply from Belfast Corporation Electricity Department and install boiler plant only to meet the steam requirements for processing and heating.

The substation on the mill premises contains three 1,250 kVA transformers stepping down the supply voltage from 6,600 to 400 volts 3-phase 50 cycles. The low-voltage side of these transformers is connected to the main switchboard shown in Fig. 2 which is of the 'OB' air-break fully interlocked steel cubicle type with a breaking capacity of 25 MVA. This switchboard comprises three 3,000 amp incoming transformer circuit-breakers and eighteen 800 amp outgoing feeder breakers, arranged in single and double tier respectively, together with instruments, meters and protective relays.

Each outgoing feeder from the main switchboard supplies a sub-distribution board of the air-break 'Combination' fuse-switch type, consisting of a fabricated steel busbar chamber mounted on floor stands and carrying the totally enclosed metalclad fuse-switch units. These boards are located at key positions in the mill and in turn feed various final-circuit totally enclosed wall mounted steel distribution fuseboards and the overhead busbar system supplying the motors of the textile machines.

The overhead busbar system of distribution is a corollary of individual motor drives in a mill or factory, enabling power to be tapped off at convenient points to suit the layout of the machines. The connections to the motors are simple and the system is economical to install and maintain. A total length of 3,720 feet of this metalclad busbar chamber with continuously insulated conductors is installed in sections near ceiling height throughout the mill, and from triple-pole outgoing fuse boxes plugged into the busbars vertical drops of cable in conduit are made to the individual motors at floor level.

All the fusegear, including the plug-in boxes of the overhead busbars, incorporates 'English Electric' high rupturing capacity non-deteriorating cartridge-type fuse links, the accurate discrimination and high operating speed of which localise interruption in the power supply and minimise damage to the electrical equipment on overloads or short-circuits. They have been proved to retain their characteristics in service for at least 25 years. The enclosure of the elements in ceramic cartridges reduces the fire risk from sparking in the inflammable atmosphere of a textile mill.

The Raw Material

Flax is a plant of which there are more than a hundred varieties. It attains a height of three to four feet in a single straight stem, and its characteristics vary with the locality where it is grown. It can be produced in any temperate climate and, in addition to France, Belgium and Ireland, it is also cultivated in certain parts of Holland and Russia.

The thin wiry stem of the plant branches out towards the top, and carries a blue or white flower

according to its variety, with the seed-boll containing linseed. The enlarged cross-sectional diagram of the stem in Fig. 3 illustrates the position of the usable fibre. As can be seen, the plant has a hollow centre, with a surround of woody matter. Around this is a thin layer, known as the Cambium layer, followed by another layer of soft pith which embraces the fibres. These fibres are arranged in small bundles each covered by a soft skin container. Finally, there is a surrounding waterproof envelope or outer layer, termed the cuticle. About two-thirds of the bulk consists of the woody centre portion, and only one-third is the useful fibre.

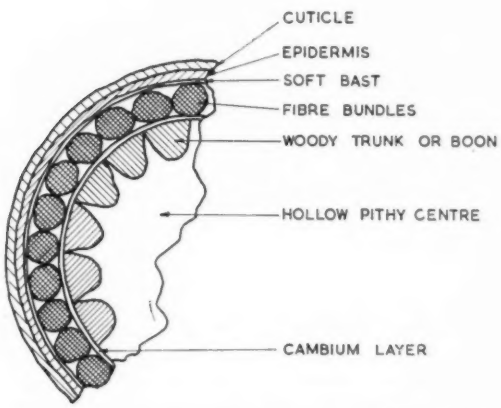


Fig. 3.—Cross section of the stem of a flax plant

The flax seed is sown in March or April and harvesting commences when the leaves turn yellow in July to August. The plant is never cut during harvesting, but is pulled up by the roots soon after the seed is formed. It is at once tied in beets, or bundles, and placed in three or four feet of water in a slanting position. Stones are used to keep them submerged, and they remain immersed for several days. This is the first treatment, known as ' retting '. Fermentation attacks the plants and breaks down the woody substance, thus facilitating the later separation of the useful fibres from the mass of pith and skin. Nowadays however many flax growers create a hastened process by using tanks containing chemicals for rapid retting.

Retting factories are situated in close proximity to the fields where the flax is grown, and after the beets have been removed from the tanks they are thoroughly dried by spreading on the grass in the meadow.

Fig. 4 illustrates the processing of the flax from these early stages right through to the final product of the spinning mill.

The dried retted flax straw is first passed through the breaker, where the straws are broken in order to loosen the adhering vegetable substances, and to render the long fibrous masses more soft and pliable. Much of the dust and shive liberated during this treatment is carried away by powerful extraction fans, when it is bagged and used for fuel.

From the breaker the flax passes to the ' scutcher ', where it is beaten by rapidly revolving blades which separate the fibres from the waste vegetable matter of the stalk. All this time, and throughout processing, the fibres are mostly of considerable length. A bunch of these resembles brown ' witches hair ' in appearance, and it is most noticeable, when efforts are made to pull them apart, that the fibres possess considerable strength.

After treatment in the scutch mill, the flax is baled and despatched to the spinning mills of Northern Ireland and other linen producing countries.

Spinning Mill Processes

On its arrival in the mill, even the best scutched flax is far from suitable for converting immediately into yarn. It has to undergo several repeated combings and cleanings to remove still further the traces of vegetable matter and loose straw which have persisted, even after the scutching in the scutch mill. After being taken from the incoming store of the mill the flax bales are opened out for the initial treatment known as ' roughing '. Handfuls of the fibres are taken and passed rapidly over what might be described as brushes having many sharp pointed steel pins instead of the bristles customary for other textiles. Much of the remaining waste substances are removed from the fibres, together with a considerable number of short lengths in a loose state. These bunches are then stored, after which they are carefully sorted into grades of various qualities, having regard to origin of growth, strength of fibre, and fibre staple length.

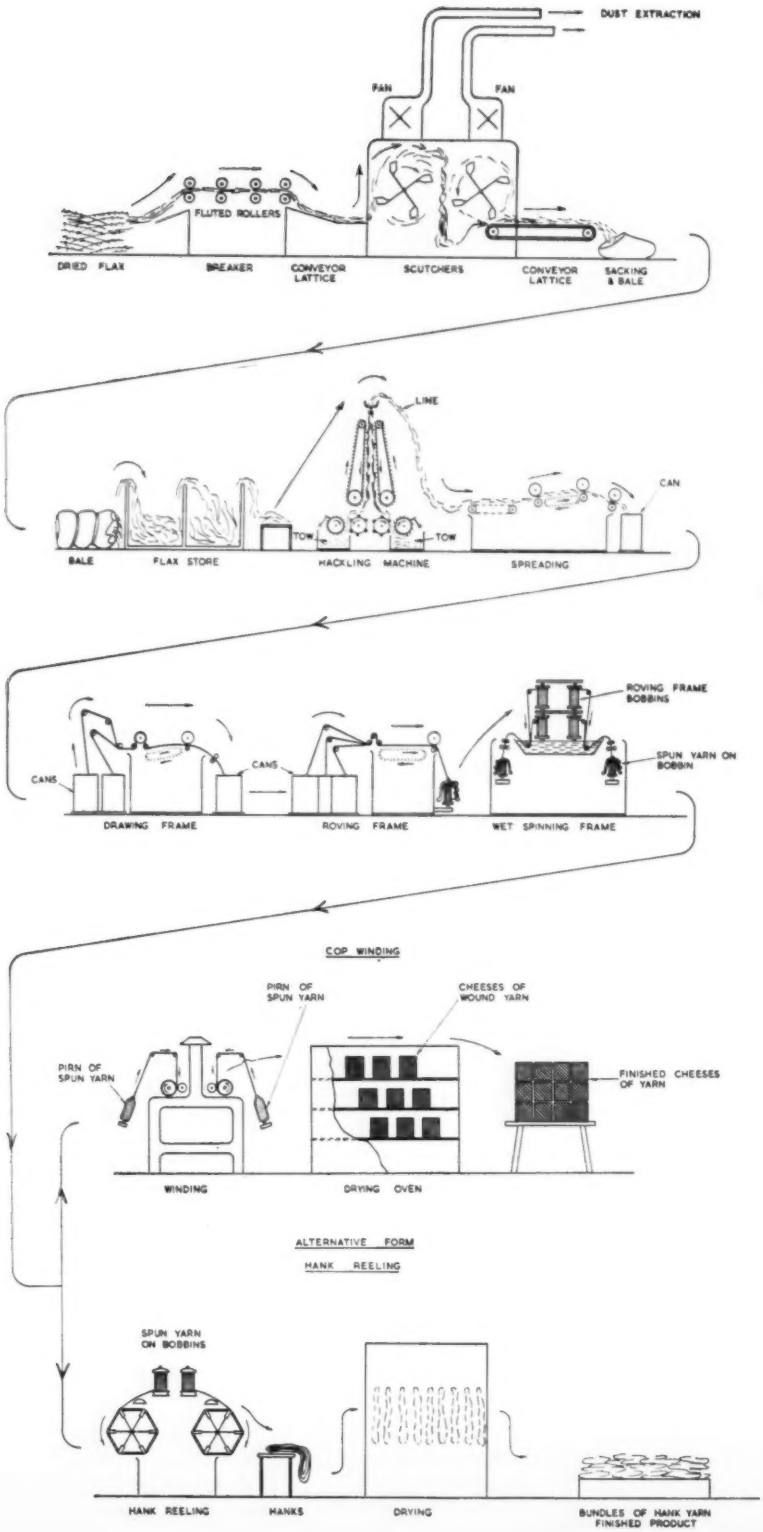


Fig. 4.—Principal processes in the spinning of flax

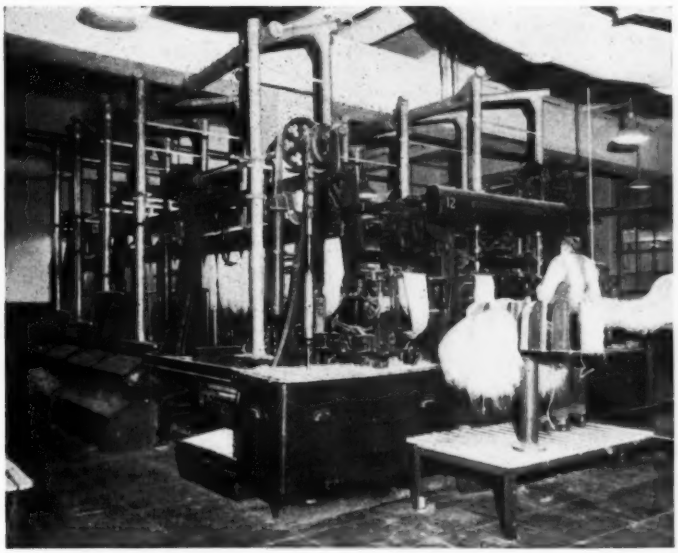


Fig. 5.—One of the hackling machines, which is driven by a 10 h.p. 725 r.p.m. straight totally-enclosed squirrel-cage induction motor

Hackling

Next comes the important stage of 'hackling'. Several of the machines used for this purpose can be seen in a modern mill, all carrying out the same operation. The hackling machine (Fig. 5) is a remarkable piece of engineering, and space does not allow a full description of its various mechanisms. However, in essence, it performs a thorough combing of the fibres. Its operation may be analogised to holding a bunch of flax fibres in one hand and combing it with the other. Then, by changing hands from top to bottom, the operation is repeated so as to comb it completely along its full length. The machine carries out these operations by automatically passing the fibres along a row of combs, from coarse pins to fine. It then moves the flax around and hackles the other end on its return journey along another set of combs.

Fibres of very different qualities are treated on the various hackling machines, and the droppings, or short fibres which are combed away, are also put to valuable use. These are known as 'Tow', whilst the longer fibres remaining after hackling are classed as 'Line'. Tow goes forward to processes which produce many of the coarser grades of commercial materials, whilst Line is used exclusively for the finer grades such as the best quality fabrics. In consequence, the hackled fibres are fed into either the Tow store or the Line store, ready for conveyance to their ensuing processes, and the flow chart, Fig. 6, describes this routing of the material in greater detail. The flow which goes through wet spinning is that for the production of yarn required for weaving purposes, while the

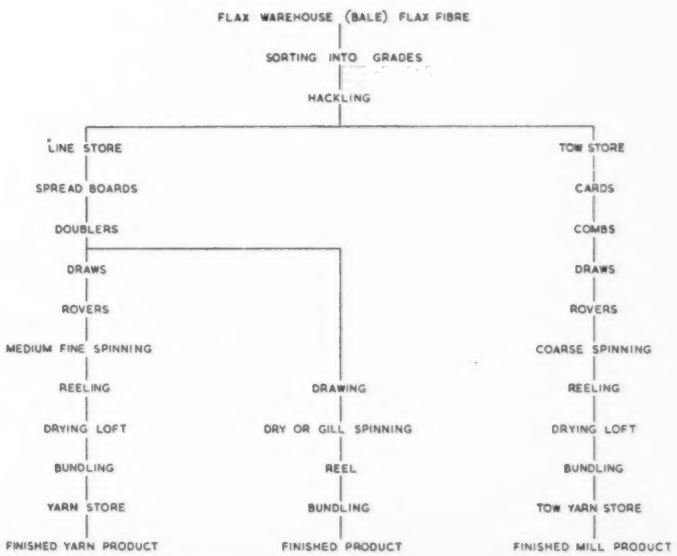


Fig. 6.—Typical flow chart of processes in a flax spinning mill

Fig. 7.—Feeding flax into the spread boards, each of which is driven by a $1\frac{1}{2}$ *h.p.* 720 *r.p.m. straight totally-enclosed squirrel-cage induction motor*

flow through dry or gill spinning is for the yarn chiefly used for linen thread manufacture.

Preparation

Line yarn production commences by treating the hackled bundles in the Preparation Room. Here there are multiples of different types of machines which are devoted to the drafting of the fibres and laying them side by side in an orderly formation. On arrival from the store, the fibres are fed into the 'spreader', or 'spread board' as it is sometimes known, Fig. 7. They are laid in little wisps on travelling bands in long continuous rows, and then passed through sets of rollers which draw one fibre lengthwise away from the other, so producing a thick ribbon of continuous length containing millions of individual fibres.

In the preparing stage Tow is subjected to two additional processes, termed carding and combing (Figs. 8 and 9). It demands a more intensive cleaning and combing treatment than Line because of its very nature after leaving the hackling machines.

Drawing

From the spreader the ribbon goes forward to the drawing machines (Fig. 10). There may be as many as four or five of these machines in a single group, the material entering the first, leaving to enter the second, and so on until the full drawing or drafting has been accomplished. At each stage

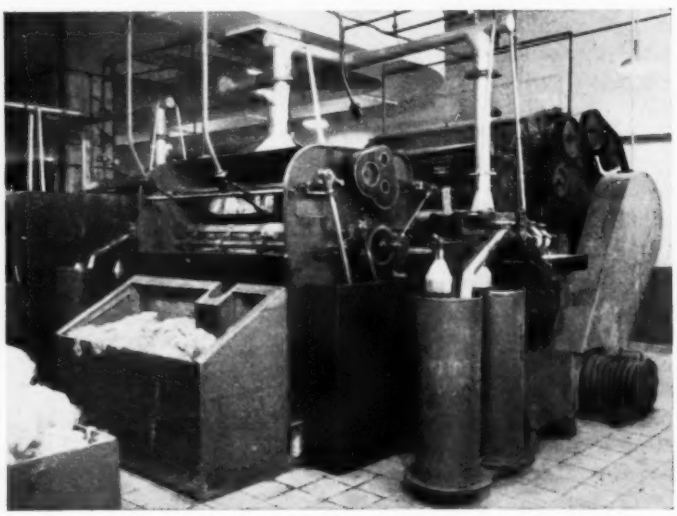


Fig. 8.—One of the carding machines for the 'Tow'. These machines are driven by high torque 6 *h.p.* 985 *r.p.m. squirrel-cage induction motors*

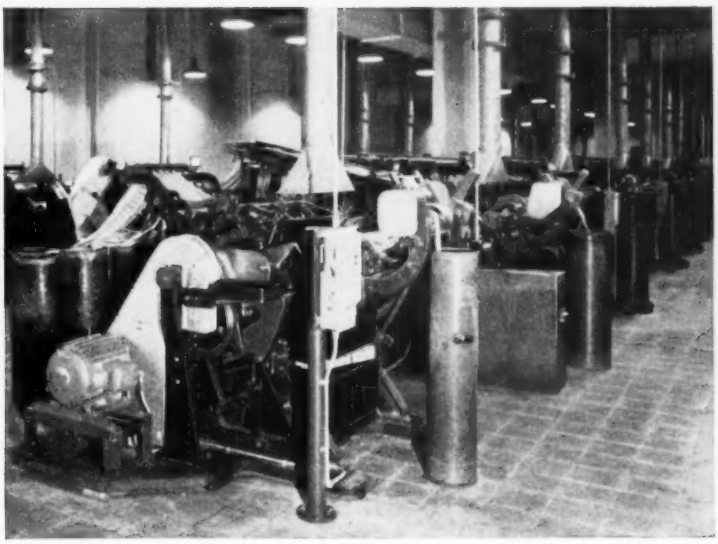


Fig. 9.—A row of combing machines for the 'Tow', each driven by a 1½ h.p. 730 r.p.m. squirrel-cage induction motor

the ribbons are drawn out longer and thinner until they are finally presented in tall circular cans to the roving frame, Fig. 12. Here the ribbon of fibres is subjected to further drafting and reduction, and then twisted for the first time into a loose thick thread, almost like knitting wool in character. The frame then winds the thread on to bobbins positioned along its length, ready for the critical operation of flax spinning.

Spinning

The filled bobbins from the roving frame are then conveyed to the spinning frames. Fig. 11 illustrates the principle of the spinning of flax. The roving bobbin is mounted in a creel and a thick thread of rove is slowly drawn through a group of drafting rollers. It is then taken up by whirling spindles rotating at speeds of about 3,000 r.p.m. The yarn is thereby given a high degree of twist which endows it with considerable strength. However, before reaching the spindles through the final rollers, the yarn passes through a trough of hot water which causes the many fibres to lie close and work smoothly in the ultimate draft and spin. This is wet spinning and is the accepted method for flax yarn. A mill so equipped has a maze of steam and hot-water pipework, all carefully controlled and regulated to give the ideal spinning conditions under which flax fibre is so sensitive.

Fig. 13 shows the spinning frames. The steam pipes can be seen, and on the right is the two-speed 8/4 h.p. 1,460/715 r.p.m. squirrel-cage

Fig. 10.—One of the drawing frames, showing its 2 h.p. 730 r.p.m. driving motor

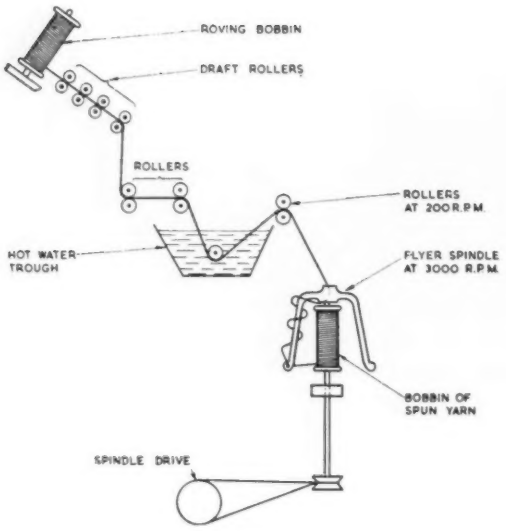


Fig. 11.—*Wet spinning of flax*

driving motor. The lower speed is used at the commencement of spinning, which is the period during which the yarn tension is greatest.

The advantages of the two-speed motor drives adopted in the spinning departments are important. By commencing the spin of a new set of bobbins at a reduced spindle speed, the operative is able to piece up the ends of yarn which may unavoidably have occurred during doffing and setting-on. The spinning frame is then brought up to its maximum speed by means of a switch which changes the pole connections on the motor.

The yarn delivered at the spinning spindles, in bobbin form, is then placed in reeling machines to be wound into large hanks. In this state it is placed in the drying loft where it is dried and conditioned, and then conveyed to the bundling room for testing and bundling, before storing in the finished yarn store.

As is often found in other sections of the textile industry, the flax spinning mills are frequently located at a considerable distance from the firms which eventually weave the yarn products into cloth, and the question is often asked why the spinning and weaving processes are not carried out under the same roof. It would appear that this is a matter of economics, in that flax spinning particularly is a highly specialised industry and only by producing on a very large scale is it possible to meet not only the stringent quality demands but the prevailing trading competition as well.

Production and Working Conditions

The careful planning of the power distribution, cabling and lighting has contributed to efficient production and a pleasing appearance within the mill. There has always been an impression that flax spinning is a comparatively dirty process,

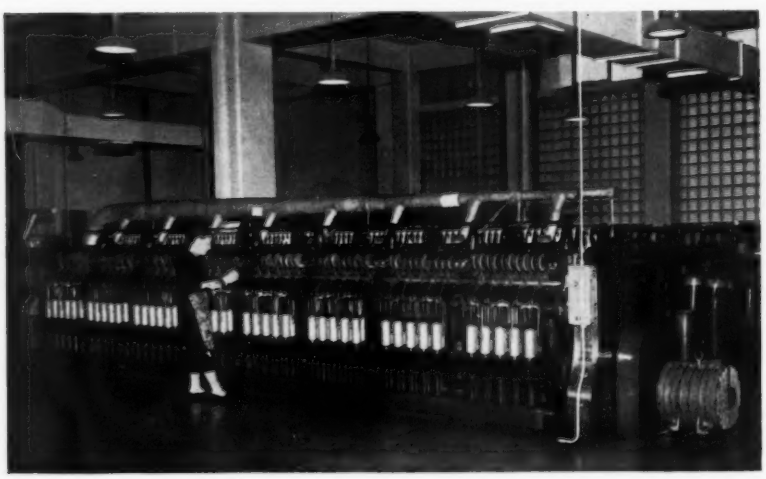


Fig. 12.—*One of the roving frames. On the right is the 6 h.p. 725 r.p.m. totally enclosed smooth-acceleration driving motor.*

Fig. 13.—*Part of the spinning room. On the right is the overhead busbar system supplying the two-speed motors which drive the spinning frames*

particularly Tow preparing and wet spinning, but this is immediately dispelled on entering the mill. The air-conditioning plant, installed by The Andrew Machine Construction Co. Ltd., is one of the most modern in industry. Air is extracted from the various departments by means of powerful fans through steel ducting to several main air-conditioning plant houses, and is filtered by bag filters. It is then passed through air washers to heating batteries and returned to the departments with a proportion of fresh conditioned air. The air temperature and humidity are automatically

Fig. 14.
The winding department

Fig. 15.
Inspection of the finished yarn

controlled, giving ideal conditions for the manufacture of flax yarns.

The fans of the air-conditioning plant are driven through vee-ropes by slipring induction motors of 35 to 140 h.p. (Fig. 16), direct-on-line started by means of contactors, and run continuously during working hours on the dust extraction and heating systems.

The whole scheme has been meticulously planned so that production proceeds at an even flow throughout the mill. An indication of the magnitude of the undertaking is given by the size of the main mill building which is 400 feet long and 150 feet wide in four floors, giving a total production area of about 7½ acres.

The large scale on which this mill has been rebuilt signifies the confidence of its owners in the future of the linen industry. The company converts raw flax into a very wide range of products, from household linen to a double damask dinner cloth. Piece goods are a very important product, particularly for export to meet the ever growing demand for high quality linens in spite of the competition from the modern synthetic fibres. Yarn and thread also provide a considerable portion of the home and export trade. The ' York Street ' Company is represented in nearly every country in the world.

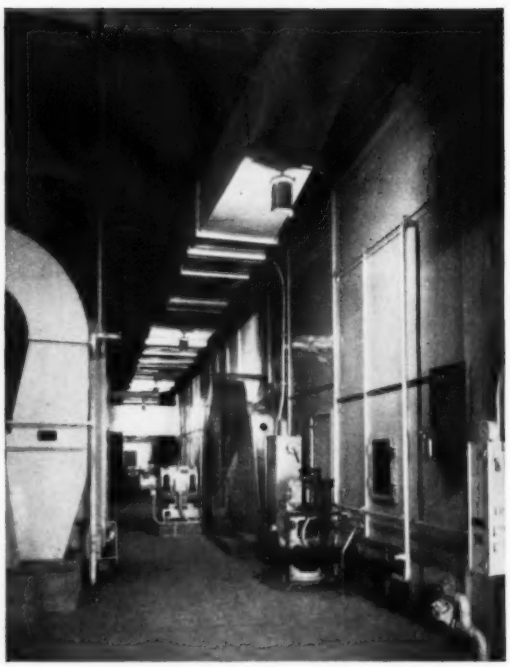


Fig. 16.—*A section of the air conditioning plant*

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